U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

SELAWIK NATIONAL WILDLIFE REFUGE OIL AND GAS ASSESSMENT

by

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EXECUTIVE SUMMARY

The area of the Selawik National Wildlife Refuge (NWR) has attracted little oil or gas exploration interest. No wells have been drilled within the refuge boundary, and only one has been drilled within 60 miles. This study of the hydrocarbon resource occurrence potential of Selawik NWR indicates that the refuge has two areas of moderate potential with the remainder of the refuge having low potential.

The smaller area of moderate potential (approximately 800,000 acres) lies along the Kobuk River valley and the Waring Mountains. It has a BLM mineral occurrence potential classification of M/A.

The larger area of moderate potential (approximately 1,100,000 acres) lies along the Selawik River valley and includes the Kobuk River delta. This area has a BLM mineral occurrence potential classification of M/C.

The remainder of the refuge (approximately 1,300,000 acres) has a low hydrocarbon occurrence potential (BLM mineral occurrence potential classificaton of L/A).

Selawik NWR has a low economic and development potential for oil and gas resources. This implies that it is very unlikely that exploration or development will occur in the refuge within the next 25 years.

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INTRODUCTION

The purpose of this report is to provide an oil and gas resource assessment of the Selawik National Wildlife Refuge (NWR) to be included as part of the "comprehensive conservation plan" for the refuge as mandated by Sections 1008 and 304(g) of the Alaska National Interest Lands Conservation Act (ANILCA). The U.S. Bureau of Land Management (BLM) is conducting the resource assessment at the request of the U.S. Fish and Wildlife Service (FWS) as set forth in a Memorandum of Understanding between the FWS and BLM (Appendix A).

This assessment will:

1. Identify areas of different hydrocarbon resource potential.

2. Illustrate and discuss a hypothetical development scenario within Selawik National Wildlife Refuge.

3. Present an economic assessment of oil and gas production from the Selawik National Wildlife Refuge.

DESCRIPTION OF GEOLOGY

Previous Work

Exploration of what is now Selawik NWR and the surrounding region began in the early nineteenth century. Through 1885, the exploration expeditions were primarily cartographic in nature and were largely conducted my military personne (Smith, 1913).

The first geologic exploration of the region was by U.S. Geological Survey (USGS) geologist W. C. Mendenhall in 1901. In 1910, Philip Smith explored the region for the USGS.

Since these early explorations many geologists, both government and industry, have worked in the Selawik-Kobuk area. The area was geologically mapped by the USGS during the late 1950s and 1960s. Little work has been done on the hydrocarbon potential of the area.

Physiography

Selawik NWR is predominantly an area of marshy lowlands in western Alaska (figure 1). The lowlands that form the main portion of the refuge are bounded on the north by the Kiana Hills, the Waring Mountains, and the Baird Mountains. The Lockwood Hills and the Zane Hills form the eastern boundary of the lowlands. The lowlands are bounded on the south by the Purcell Mountains and the Selawik Hills. Selawik Lake and Hotham Inlet bound the lowlands to the west and form the western boundary of the refuge.

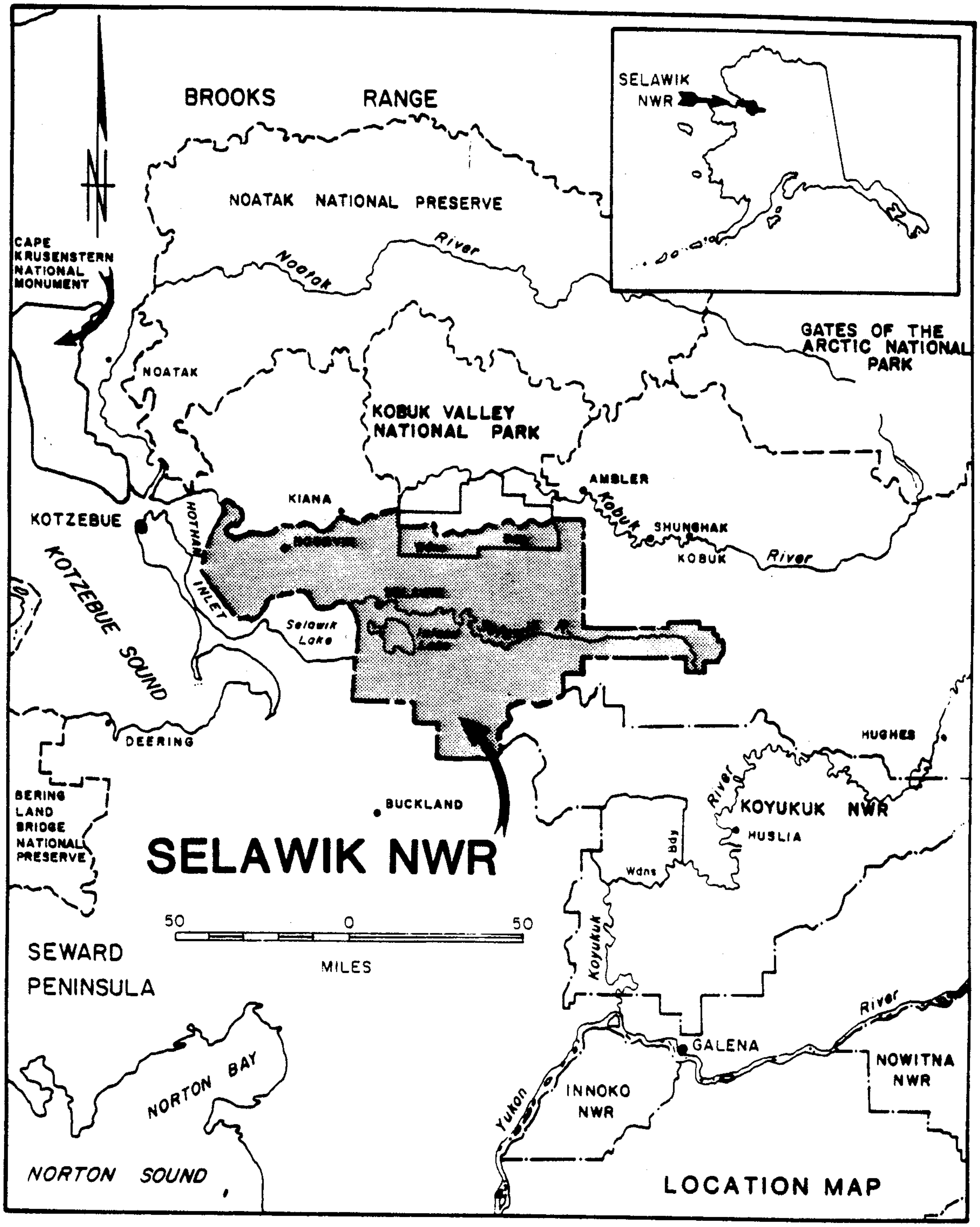

Figure 1. Location map of Selawik National Wildlife Refuge.

Selawik NWR lies within the western Alaska province of the Intermontane Plateaus physiographic division of the North American Cordillera (Wahrhaftig, 1965). The refuge contains portions of four physiographic sections; the Pah River section, the Kobuk-Selawik Lowland, the Selawik Hills, and the Buckland Lowland (figure 2).

The Pah River section is an area of varied topography. There are areas of lowlands bounded by "rolling" plateaus and ranges of hills and low mountains (elevations greater than 3,200 feet within the refuge). The lowlands contain numerous lakes, meandering streams, and extensive marshy areas. The hills and mountains are gently rounded at the lower elevations, becoming more rugged at the higher elevations where glaciation has occurred (Wahrhaftig, 1965).

The Kobuk-Selawik Lowland is chiefly "broad river flood plains and lake-dotted lowlands" that are generally marshy or tundra covered. The Waring Mountains are actually low, rounded hills lying between the Kobuk and Selawik rivers in the northern part of the refuge. They have elevations less than 2,000 feet. Streams within this section are generally meandering, of low gradient, and have numerous side sloughs (Wahrhaftig, 1965).

The Selawik Hills are gentle hills with well rounded or flat summits as high as 2,200 feet within the refuge.

The Buckland River Lowland is an area of gently rolling topography with slopes of only a few feet in a mile. A few lakes are present in this section within the refuge (Wahrhaftig, 1965).

Rock Units

Selawik NWR is almost entirely within the northern Yukon-Koyukuk province (YKP). The portion of the refuge that is not within the YKP is the Kobuk River delta. The YKP is not the simple sedimentary basin of Payne (1955) and Miller, Payne, and Gryc (1959), but is a highly mobile tract subjected to repeated volcanism and plutonism during Cretaceous and Tertiary times (Patton, 1973).

The area studied for this report includes the mafic volcanic and intrusive rocks and the metamorphic complexes that lie to the north and east of YKP. These rocks were studied because they are the source for many of the sediments in the refuge. In addition, an understanding of the processes that formed these rocks is crucial to understanding the processes that occurred within the refuge.

Rocks of the northern YKP are chiefly volcanogenic sediments and andesitic volcanics of Early and Late Cretaceous age, which have been intruded by Cretaceous granitic rocks and are locally overlain by Late Cretaceous and Cenozoic volcanic rocks. Sedimentation was limited to a single episode in mid-Cretaceous (Albian and Cenomanian) time (Patton, 1973). The YKP is best described as a volcanic or volcanogenic province rather than a sedimentary basin.

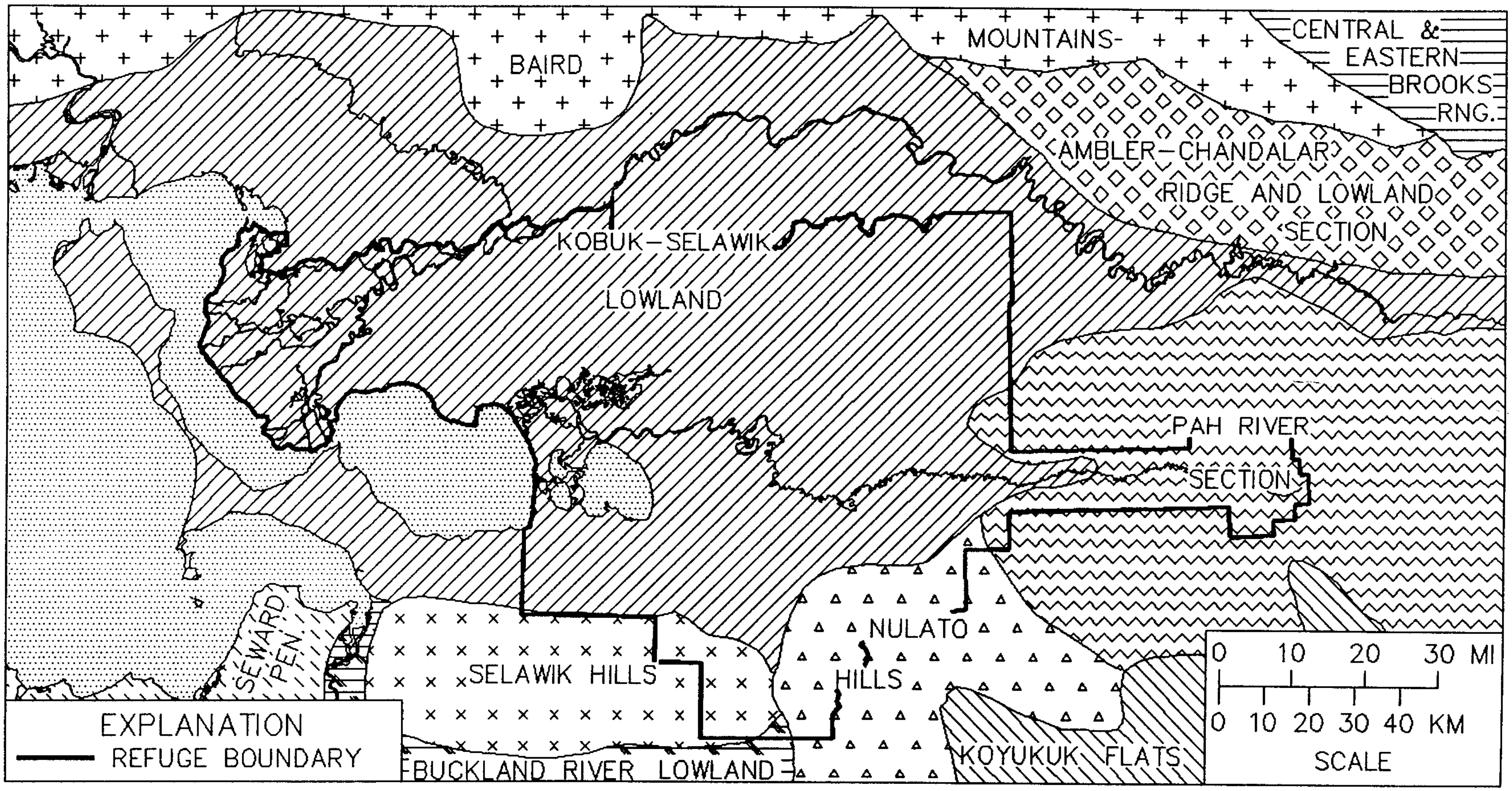

Figure 2. Major physiographic divisions of Selawik NWR (from Wahrhaftig, 1965).

The rocks in the study area range in age from Precambrian(?) to Quaternary. See figure 3 for a stratigraphic column. Figures 4 and 5 contain northwest-southeast and north-south cross sections that show the structural relationships of all the rocks within the refuge.

Precambrian to Devonian

The northern portion of the study area (outside the refuge) is partially composed of a metamorphic complex, known as the southern Brooks Range or Ambler schist belt. The schist belt has been assigned a Devonian or older (?) age by Patton, Tailleur et al (1977), and a Late Precambrian age by Forbes, Camden et al (1979) and Turner, Forbes, and Dillon (1979a). The schist belt is composed chiefly of greenschist facies rock that locally contains blueschist mineral assemblages (Patton, Tailleur et al, 1977). These rocks include metarhyolite, muscovite-quartz schists, greenstone, calc-mica schists, marble, quartzite, chlorite schists, amphiobolite schists, phyllite, and serpentinite. The precursors or protoliths of these rocks included both mafic and felsic volcanic rocks, limestone, dolomite, and pelitic sediments.

Permian to Jurassic

There are extensive exposures of mafic volcanic and intrusive rocks in the northern part of the study area. These rocks were apparently part of an ophiolite sequence, composed of pillow basalt, diabase, gabbro, radiolarian chert, serpentinized periodotite and dunite, and slate. All of the volcanic and intrusive rocks have undergone metamorphism to the greenschist facies, forming greenstone. Some of these rocks have been intruded into the metamorphic rocks of the schist belt, or tectonically emplaced in them.

Lower Cretaceous (Neocomian)

The base of the Cretaceous sequence in the northern YKP is composed of marine andesitic volcanic rocks that apparently underlie nearly the entire province (Patton, 1973). Aeromagnetic profiles suggest that they may also underlie large parts of the Kobuk-Selawik Lowlands (Patton and Miller, 1968; Patton, Miller, and Tailleur, 1968). This assemblage of rocks is composed predominantly of volcaniclastic rocks, but also contains porphyritic pyroxene andesite flows and fine grained intrusive rocks. The volcaniclastic rocks of this assemblage include crystal and lithic tuffs, massive breccias, agglomerates and conglomerates, and tuffaceous graywacke and mudstone. Lenticular masses of shelly limestone forms lenticular masses are intercalated with the volcanic rocks in the Kobuk valley. Along the Hogatza plutonic belt, the volcanic rocks have been propylitically altered to a hard, pale-green hornfels (Patton, 1973).

AGES	STRATIGRAPHIC UNITS
QUATERNARY	Basalt, glacial drift, waterlaid and windblown silt deposits
TERTIARY 43–44Ma	Basalt $\pm$ Felsic Volcanic Rocks
TERTIARY 50–65Ma	Felsic Volcanic Rocks $\pm$ Basalt
MIDDLE–LATE CRETACEOUS	Quartz conglomerate, sandstone, shale, and coal (nonmarine marginal trough deposits)
	Graywacke, mudstone, shale, conglomerate, tuff, and coal (fluvial–deltaic deposits)
	Volcanic graywacke, conglomerate and mudstone (flysch deposits) intruded by 79–89ma calc–alkaline plutonic rocks
NEOCOMIAN	Andesitic volcanic rocks and volcanogenic sediments intruded by 100–113ma alkalic plutonic rocks
JURASSIC TO PERMIAN	ANGAYUCHAM TERRANE Pillow basalt, gabbro, serpentinized peridotite and dunite, chert and slate
DEVONIAN TO PRECAMBRIAN	RUBY TERRANE Pelitic schist and carbonate rocks

Figure 3. Stratigraphic column of Selawik NWR (after Patton, 1973, in Harris, 1987).

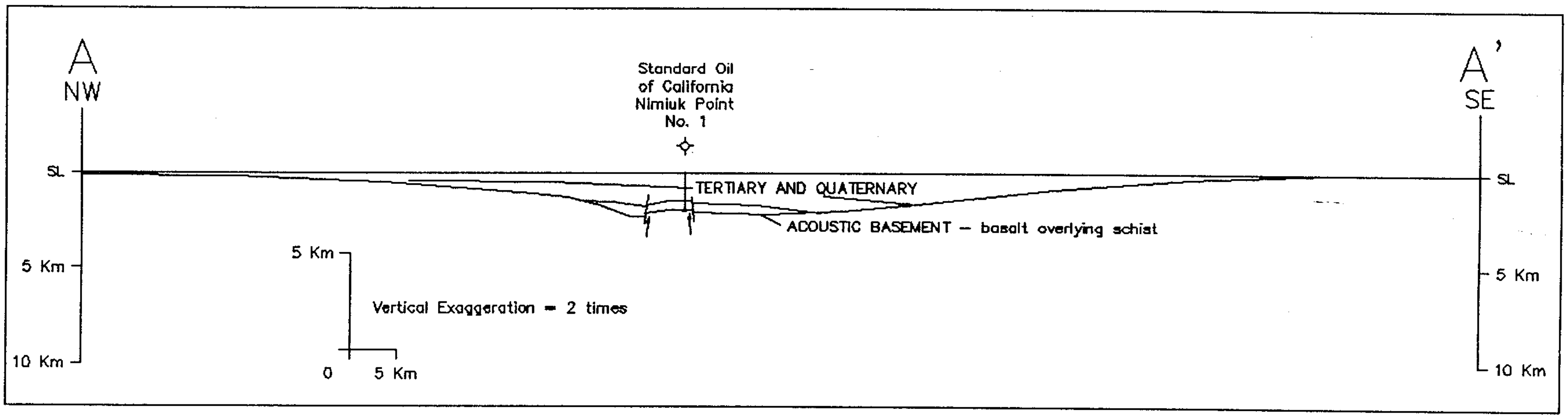

Figure 4. Northwest to southeast cross section through the Standard Oil of California Nimiuk Point No. 1 (after Ehm, 1983). See Plate 1 for location of section.

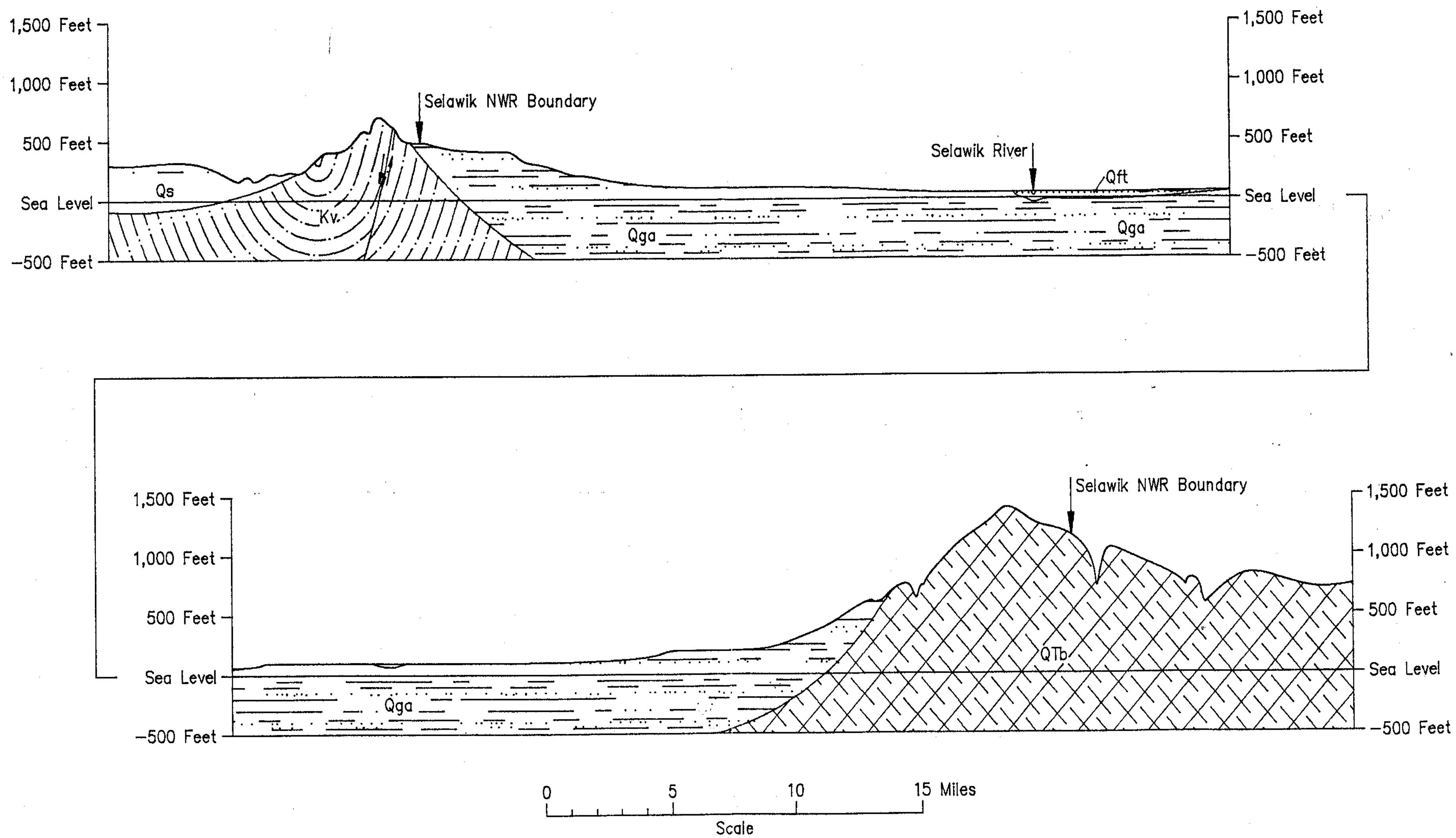

Figure 5. Cross section B–B', a north–south cross section through Selawik NWR. See Plate 1 for location of section. See Appendix D for explanation of geology. Horizontal scale = 1:250,000. Vertical scale = 1:12,000. Vertical exaggeration = 20.8.

Lower and Upper Cretaceous

Cretaceous terrigenous sedimentary rocks underlie a large portion of the northern YKP, but only the northern half of the refuge (see plate 1). During Lower Cretaceous (Albian) time, thick sequences of marine turbidites, chiefly volcanic graywacke and mudstone, accumulated in the Kobuk trough. These sediments are known to be as much as 5,000 feet thick and may aggregate more than 20,000 feet in some locations (Patton, 1973). In the study area, as much as 5,000 feet of shallow-water calcareous graywacke and mudstone overlie the Lower Cretaceous turbidites. Near the Kobuk River delta these Lower to Upper Cretaceous (Albian and Cenomanian) calcareous graywackes and mudstones grade upward into conglomeratic coal-bearing deposits. Along the northern edge of the YKP (and refuge), at least 3,000 feet of nonmarine conglomerate of Upper Cretaceous (Santonian(?) and Campanian) age unconformably overlie the Albian and Cenomanian graywackes and mudstones. These deposits also contain minor amounts of quartz sandstone, shale, thin bituminous coal beds, and ash fall tuffs (Patton, 1973). These sediments were transported from both the north and south into the Kobuk trough.

The Hogatza plutonic belt extends across the southern part of the study area (plate 1). This belt of granitic rocks contains several separate plutons having compositions monzonite, syenite, quartz monzonite, and granodiorite with some minor alkaline subsilicic rocks. The plutons intrude both the Lower Cretaceous andesitic volcanic rocks and the Lower Cretaceous sedimentary rocks. They appear to be related both spatically and temporally to the Upper Cretaceous felsic volcanic rocks.

Upper Cretaceous and Lower Tertiary

Extrusive and intrusive felsic rocks, chiefly latites and rhyolites, were emplaced in the YKP in Upper Cretaceous and Lower Tertiary time. Subaerial flows and tuffs, up to 2,000 feet thick, overlie the earlier Cretaceous andesitic volcanic rocks and sedimentary rocks. Locally swarms of small sills, dikes, and plugs of latite and rhyolite pervasively intrude the older Cretaceous volcanic and sedimentary rocks.

Tertiary

During Tertiary time, several small structural or topographic basins in the YKP were filled with nonmarine and shallow marine sands, silts, and gravels. One of these basins, the Selawik Basin, extends from Kotzebue Sound up the Selawik River.The Basin contains lignitic coal in a sequence of sand and gravel (Patton, 1973).

Upper Tertiary(?) and Quaternary Rocks

In the southern part of the study area, there are flatlying flows of olivine basalt that may be as much as 500 feet thick. The flows are frequently mantled in wind-blown silts and glacial drift (Patton, 1973).

Quaternary

All of the river valleys and lowlands in the study area are covered with sequences of alluvium, eolian deposits, flood plain deposits, and glacial drift of quaternary age. The eolian deposits include the Great Kobuk and Little Kobuk Sand Dunes. In the major river valleys, the flood plain deposits may reach significant thicknesses.

STRUCTURAL GEOLOGY AND TECTONICS

Structural Geology

Early workers such as Miller, Payne, and Gryc (1959) considered the study area to be underlain by the Yukon-Koyukuk geosyncline, the Hogatza arch, the Kobuk trough, and the southern foothills of the Brooks Range. The Yukon-Koyukuk geosyncline, the Hogatza arch, and the Kobuk trough are all currently considered to be part of the Yukon-Koyukuk geological province (YKP).

The basic structure of the study area is basically a broad structural high in the southern portion and a Cretaceous sedimentary basin to the north. The structural high is composed of volcanic rocks and underlies the southern two-thirds of the refuge. Plate 1 shows the probable southern limit of Cretaceous sedimentary rocks. The sedimentary basin is known as the Kobuk-Koyukuk basin or the Kobuk trough and may be filled with more than 20,000 feet of volcanic graywacke and mudstone and nonmarine trough margin deposits (Patton, 1973).

All pre-Tertiary rocks in the northern YKP are intensely deformed and characterized by steep dips, tight folds, and closely spaced high-angle faults (Patton, 1973). In the study area, the folds and faults trend east-west. The extent of deformation in the YKP is proportional to the age of the rocks as the YKP has undergone several periods of deformation (Harris et al, 1987). Along the northern margin of the YKP, the Kobuk fault zone extends for more than 300 miles and may be as much as 20 miles wide. The Kobuk trough lies within the fault zone. The nature of the fault zone is in dispute as Grantz (1966) considers it a strike-slip fault, while Patton, Miller, and Tailleur (1968) and Hitzman et al (1982a) consider the movement to have been vertical.

The Selawik Basin is a structural basin that underlies the western Selawik River valley, most of Kobuk Delta, and the offshore areas west of the refuge.

The rocks of the southern Brooks Range are intensely deformed with extensive folding and possible nappe structures in the Schwatka Mountains (Mull, 1977) (figure 6). There are at lease four thrust faults in the Cosmos Hills (Sichermann, et al, 1976). These structural styles can probably be extended both east and west from these areas.

Figure 7 shows the location of the Selawik Basin, the Kobuk trough, and the Hogatza arch.

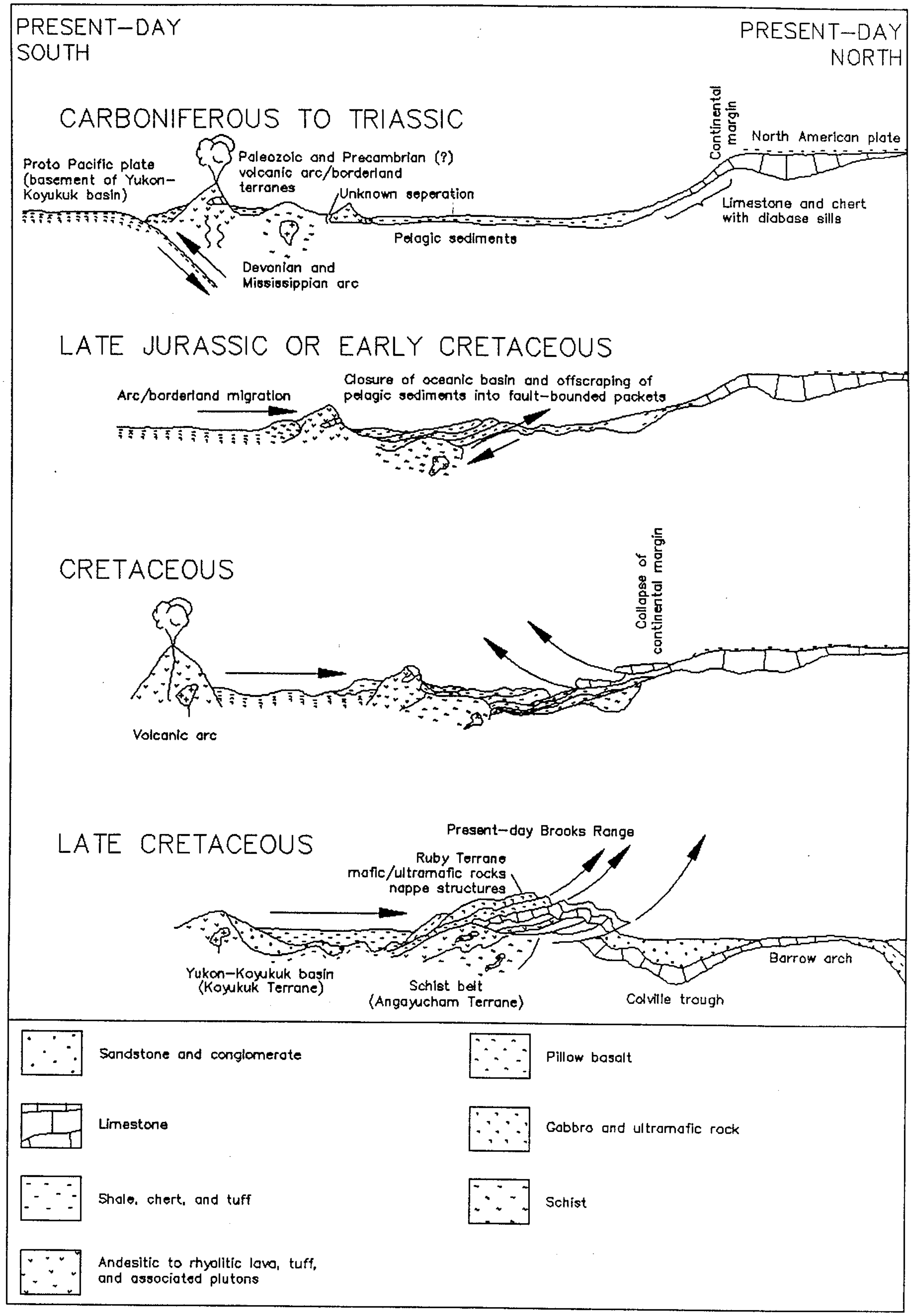

Figure 6. A series of sketches showing the structure and relationships between the Koyukuk, Angayucham, and Ruby terranes (after Churkin, Nokleberg, and Huie, 1979).

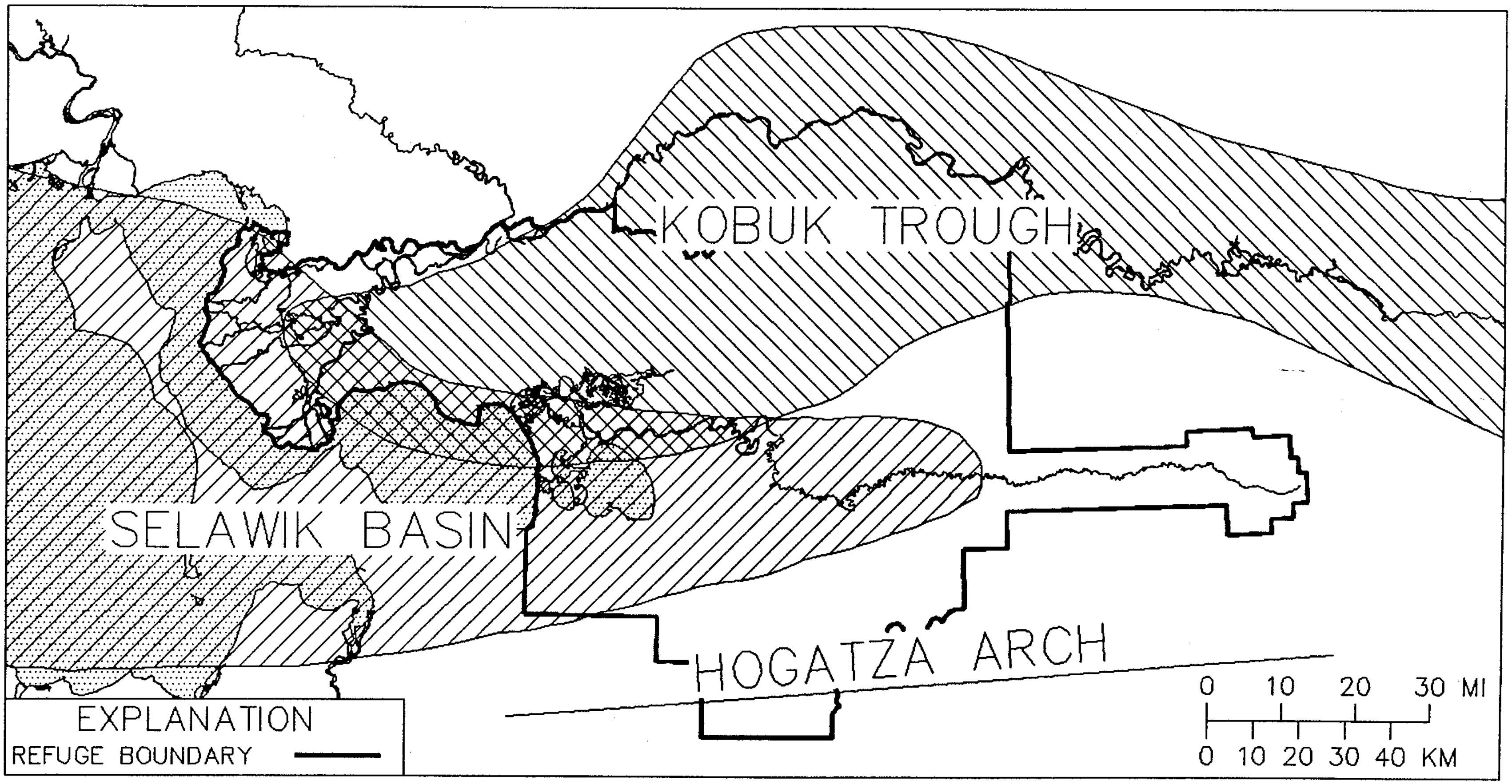

Figure 7. Major structural features of Selawik NWR (after Miller, Payne, and Gryc, 1959).

Tectonics

The Yukon-Koyukuk geologic province (YKP) corresponds to the Koyukuk lithotectonic terrane of Jones, Silberling, Coney, and Plafker (1987). A terrane is a fault-bounded geologic entity of regional extent, which is characterized by a geologic history that is different from the histories of contiguous terranes (Jones et al, 1985). The study area also contains portions of the Angayucham Terrane (Jones, Silberling, Coney, and Plafker, 1987) and the Ruby Terrane (Jones, Silberling, Berg, and Plafker, 1981). Jones, Silberling, Berg, and Plafker did not recognize the Koyukuk Terrane as such in 1981. Figure 8 shows the location of these terranes in the study area.

The Koyukuk Terrane is thought to have originated as a rift zone (Patton, 1975). The oldest rocks in the terrane are pillow basalts, diabase, gabbro, and ultramafics, apparently an ophiolite sequence, that are believed to represent oceanic crust and mantle material from the floor of the rift. Cretaceous volcanics and intrusives overlie this oceanic crust and make up most of the rock exposed in the study area south of the Arctic Circle.

The Angayucham Terrane is a structurally and stratigraphically complex assemblage of oceanic rocks, including gabbro, diabase, pillow basalt, tuff, chert, graywacke, argillite, and minor limestone. Plutonic ultramafic rocks have been tectonically emplaced throughout the terrane (Jones, Silberling, Coney, and Plafker, 1987).

The Ruby Terrane is a structurally complex and polymetamorphosed sequence of middle Paleozoic and older carbonate rocks Ii.e., the Skagit Limestone), calc-schist, quartz-mica schist, quartzite, metarhyolite, chert, and argillite (Jones, Silberling, Coney, and Plafker, 1987).

The Ruby Terrane is the oldest of the three terranes, and may be the basement for the entire YKP (Gemuts et al, 1983). During the Late Jurassic or Early Cretaceous, the rocks of the Angayucham Terrane were thrust over the Ruby Terrane. During this same time period, the oceanic arc that is the Koyukuk Terrane collided with the continental margin. Outlyers of Angayucham Terrane rocks in the Brooks Range indicate that the extent of Angayucham Terrane rocks was once much greater than at present. Angayucham Terrane rocks probably form the basement under the YKP. The suture zone between the Koyukuk Terrane and the Ruby ad Angayucham Terranes is now known as the Kobuk fault zone. Figure 6 presents a pictographic representation of the events discussed above.

Geologic History

The rocks and sediments in the study area for the Selawik NWR oil and gas assessment range in age from Precambrian to Recent. The oldest rocks occur north of the refuge in the Ruby Terrane. The rocks of the Angayucham and

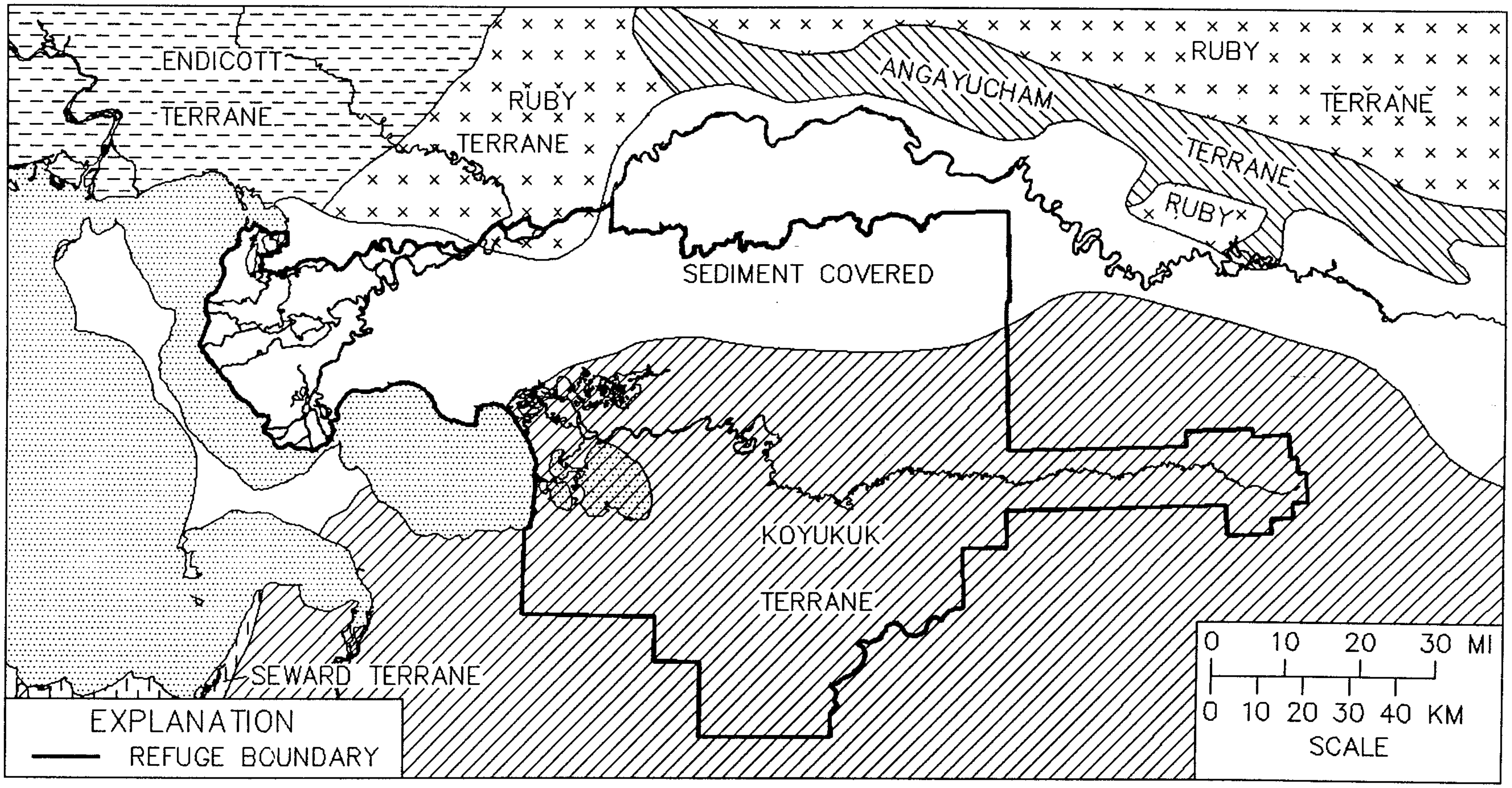

Figure 8. Lithotectonic terrane map of Selawik NWR (after Jones, Silberling, Coney, and Plafker, 1987, and Jones, Silberling, Berg, and Plafker, 1981).

Koyukuk Terranes range in age from Paleozoic to Recent. As long as the terranes were separate with differing histories, they will be discussed separately, after that, they will be discussed together.

Ruby Terrane

The basement rocks of the Ruby Terrane were deposited in a marine environment and consisted of marine sedimentary and mafic volcanic rocks (Turner, Forbes, and Dillon, 1979) of Precambrian age. These rocks underwent regional metamorphism to the blueschist facies during the Late Precambrian (Turner, Forbes, and Dillon, 1979). (The tectonic event that caused this metamorphism was a compressive event and may have been Precambrian subduction.)

Marine sedimentation continued into the Paleozoic, with limestones being deposited from the Middle Devonian through the Early Mississippian (Smith et al, 1978). Turner, Forbes, and Dillon, (1979a) suggest that carbonate deposition may have begun as early as the Silurian. This limestone may be a correlative of the Skagit Limestone (Sichermann et al, 1977). Turner, Forbes, and Dillon, (1979a) propose that these carbonates and the underlying metamorphic rocks were then intruded by Middle Devonian granitic plutons and hypabyssal felsic intrusives. Related felsic volcanism and carbonate deposition also occurred at this time, forming a laterally extensive Devonian volcanogenic sequence in an ensialic island arc or a magmatic belt on a submerged continental margin (Dillon, Pessel et al, 1980). Volcanogenic stratiform sulfides were deposited in this sequence during the Middle to Late Devonian (Hitzman et al, 1983). The Late Devonian was also a period of carbonate deposition on the horsts and deep water sedimentation and bimodal volcanism in the intervening grabens associated with a rifted continental margin (Hitzman et al, 1983). Deposition of marine sediments may have continued as late as the Triassic (Box, 1985).

During the Jurassic and Early Cretaceous, rocks of the Angayucham Terrane were thrust over the rocks of the Ruby Terrane. This compressive tectonic event caused intense deformation and greenschist metamorphism in the rocks of the Ruby Terrane (Churkin, Nokleber et al, 1979a; Turner, Forbes, and Dillon, 1979a). The metamorphic grade of the Ruby Terrane rocks increases to the north (Forbes, Cander et al, 1979).

Angayucham Terrane

The Ruby Terrane faced an area of open ocean to the south during the Devonian. Deep water marine sediments were being deposited on an oceanic crust (Roeder and Mull, 1978). During the Mississippian through the Triassic, a series of sea floor basalts were erupted onto the Devonian sediments. During the Mesozoic, probably Late Triassic or Early Jurassic, an incomplete ophiolite sequence, including mafic and ultramafic cumulates and remnants of a sheeted dike complex, was thrust over the Mississippian and Triassic pillow basalts. These Devonian through Triassic sediments and basalts with the structurally overlying ophiolite sequence form the Angayucham Terrane. This terrane was thrust over the Ruby Terrane rocks during the Jurassic and Early Cretaceous.

Koyukuk Terrane

Currently, there are three different theories to explain the formation of the Koyukuk Terrane. Two of the theories result in similar hydrocarbon occurrence potentials for Selawik NWR, while the third theory would result in a different hydrocarbon occurrence potential.

Theory 1 - Gemuts et al, 1983 (figure 9)

During the Early and pre-Devonian, the area of the Koyukuk Terrane was an area of Precambrian and early Paleozoic continental crust, although it may have been submerged. During the Devonian, rifting began along the present-day Kobuk fault zone and along a zone running from the eastern end of the Kobuk fault zone to the southwest. The chert, mafic volcanic and volcaniclastic rocks, and associated mafic and ultramafic intrusive rocks of the Angayucham Terrane were generated in these rifts. Rifting continued into the Triassic.

Beginning in the Jurassic and continuing into the Early Cretaceous, a compressional event forced the wedge that had been rifted out of the continental mass back into what was essentially its original position, thrusting the oceanic crust that had been formed over the surrounding continental rocks (Ruby Terrane). The wedge of continental crust that was rifted away from the continent forms the Koyukuk Terrane.

The Nimiuk Point No. 1 well, approximately 15 miles southeast of Kotzebue and 7 miles west of the refuge, contains what is apparently continental crust from about 5,960 feet to its total depth at 6,311 feet. These rocks are metamorphic rocks that are similar in nature to the rocks of the schist belt (Ruby Terrane). Gemuts et al (1983) report that upper-amphibolite-grade metamorphic rocks are present in the Selawik Hills and interpret them as continental basement, supporting the above theory.

Theory 2 - Patton, 1975; Cavalero, 1983 (figure 10)

Prior to the Early Devonian, there was continental crust in the present-day location of the Koyukuk Terrane. During the Early Devonian, rifting began to open an ocean basin in the location of the present-day Koyukuk Terrane, pushing the continental crust that was occupying that location to the south. As this was occurring, there was felsic arc volcanism along the continental margin to the north. A basaltic, oceanic arc was being generated to the south during Middle to Late Devonian.

During the Triassic or Early Jurassic, this ocean basin began to close. During the Late Jurassic or Early Cretaceous, the oceanic arc collided with

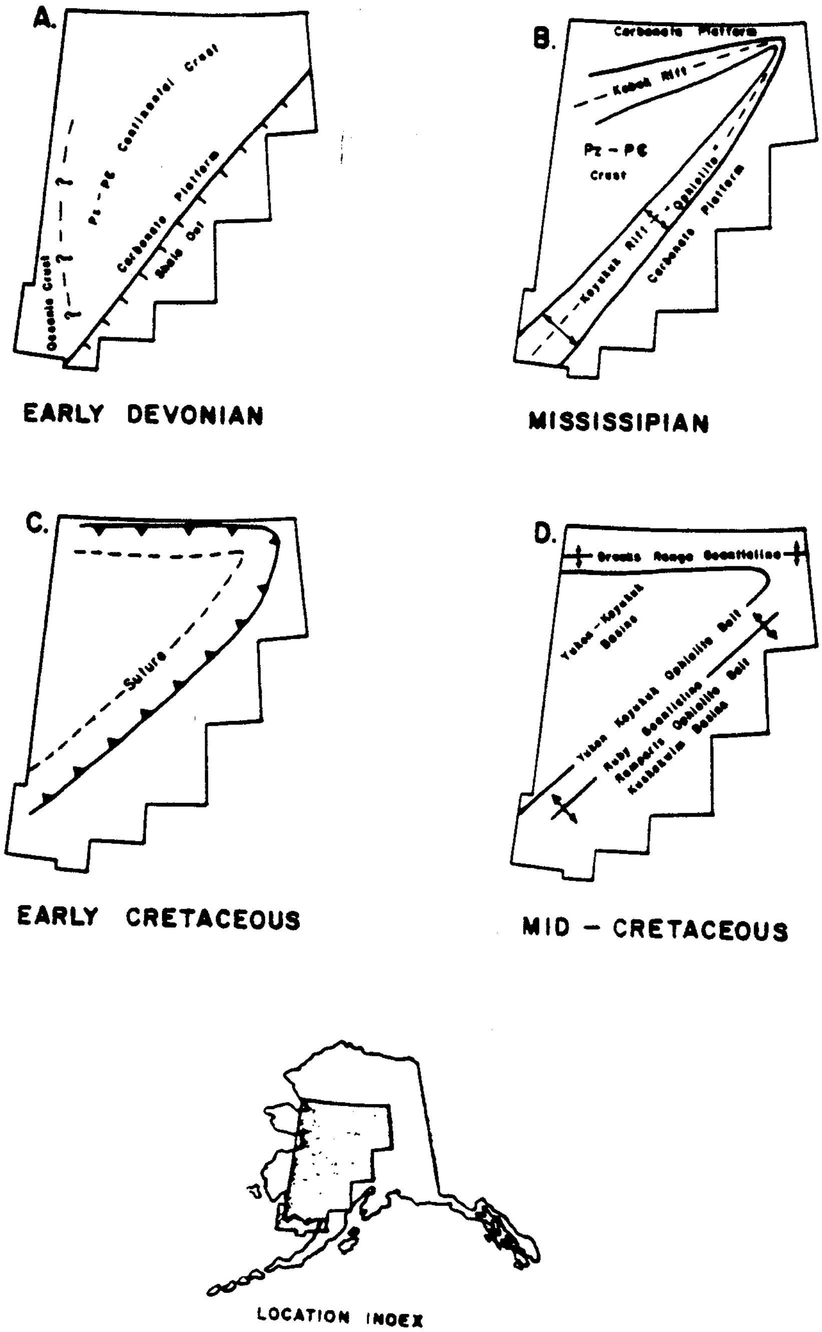

Figure 9. Pictographic representation of theory number 1 of the history of the Koyukuk Terrane (after Gemuts et al., 1973).

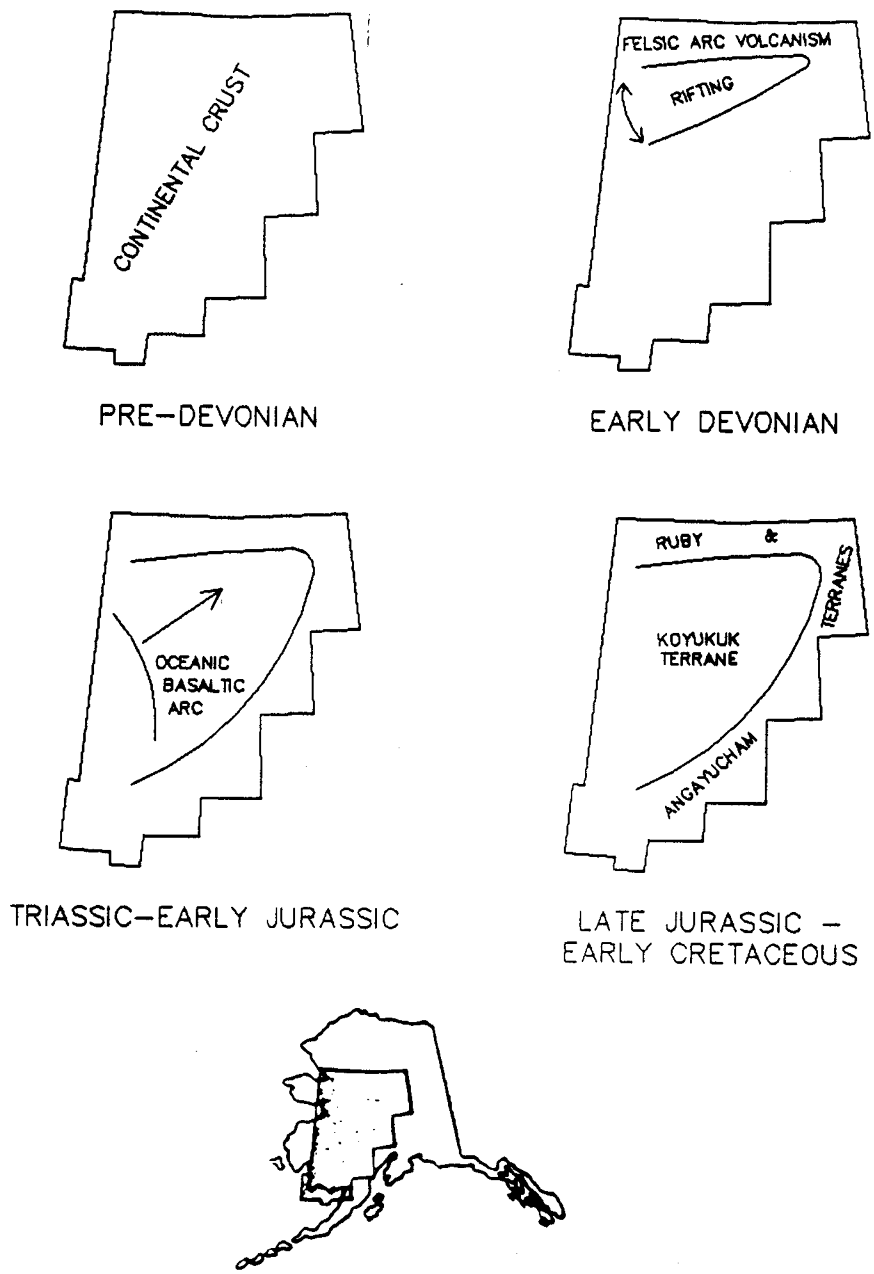

Figure 10. Pictographic representation of theory number 2 of the history of the Koyukuk Terrane.

the continental margin, and oceanic rocks of the Angayucham Terrane were thrust over the continental rocks to the north (Ruby Terrane). The oceanic arc sequence of sediments form the Koyukuk Terrane.

The types of volcanism and sedimentation associated with the area are similar to that associated with an ongoing arc-continent collision in eastern Taiwan (Box et al, 1984). Patton (1973) indicates that the rocks of the Angayucham Terrane dip beneath the rocks of the Koyukuk Terrane. The geochemistry of the granitic plutons in the Koyukuk Terrane indicates that there may be an oceanic crust beneath the YKP (Arth et al, 1984). Isotopic and gravity data indicate that the continental rocks do not extend under the YKP (Patton and Box, 1985). Some of the evidence presented here for theory 2 is in direct conflict with theory 1.

Theory 3 - Box, 1985; Box and Patton, 1985 (figure 11)

During the pre-Cretaceous, the area of the present-day Koyukuk Terrane was an ocean basin with continental crust to the north and southeast, and with an oceanic arc to the southwest. During the Early Cretaceous, the oceanic arc collided with the continental margin, and fitted itself to the shape of the margin. Oceanic crust (Angayucham Terrane) was thrust over the continental margin (Ruby Terrane) during the collision. The oceanic arc volcanics and volcaniclastic sediments form the Koyukuk Terrane. During the Late Cretaceous, the continental crust of the Seward Peninsula was rotated around the western side of the Koyukuk Terrane and emplaced in its present position.

All of the evidence for theory 2 also applies to theory 3. One of the originators of theory 2 has now accepted this version (Patton).

During the mid-Pleistocene, the Brooks Range was subject to extensive glaciation, possibly of ice-cap proportions. This period of glaciation extended as far south as the southern shore of Selawik Lake (Fernald, 1964). This period of glaciation, known as the Kobuk Glaciation, may be Illinoian in age. Extensive dune fields and sand blanketed the area of Selawik NWR.

During the mid-Pleistocene, there was an interglacial period between the Illinoian and Wisconsinan glacial periods, the Sangamon interglacial. During this time period, much of the lower portions of Selawik NWR were covered by a marine transgression. Sea level at that time was 22 to 33 feet (7-10 meters) higher than at present (Pewe, 1975).

During Wisconsinan time, Late Pleistocene, the Brooks Range was again a center for glaciation. This period of glaciation did not extend as far south as the refuge, and left moraines in the larger valleys of the Brooks range only. This period of glaciation is known as the Ambler(?) glaciation (Fernald, 1964). This was again a time of deposition for extensive eolian and alluvial deposits.

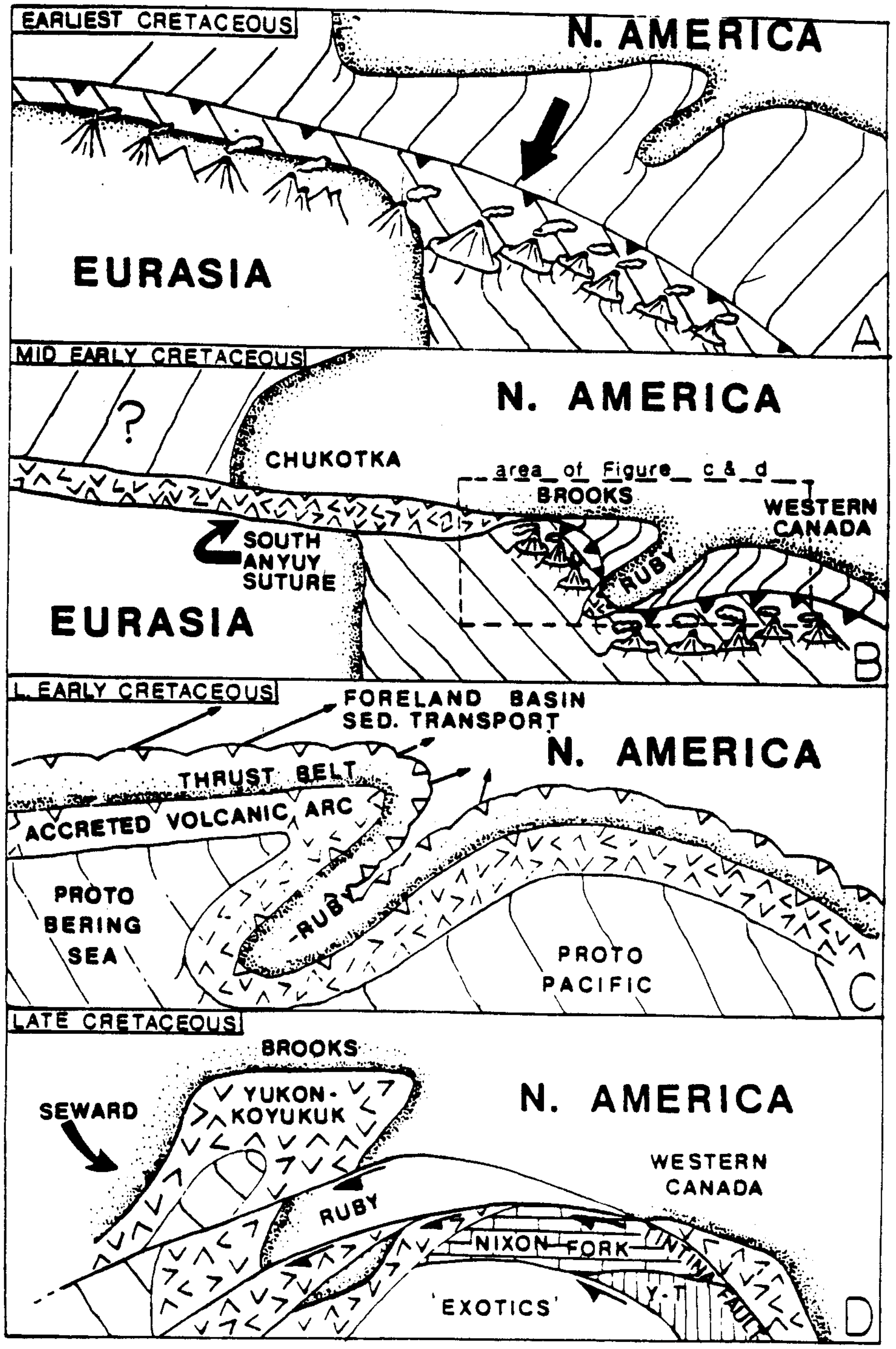

Figure 11. Pictographic representation of theory number 3 of the history of the Koyukuk Terrane (from Box, 1985).

A later period of glaciation, called the Walker Lake Glaciation, produced a set of moraines in the river valleys of the Brooks Range. This period of glaciation may range in age anywhere from Wisconsinan to Recent (Fernald, 1964).

The Jade Mountains were the only location within the study area that were glaciated during the Ulaneak Creek Glaciation during the latest Wisconsinan or Holocene (Recent).

GEOCHEMISTRY

There is limited petroleum related geochemical information for the Selawik NWR. Geochemical analyses were performed on samples from the Standard Oil of California Nimiuk Point No. 1 and on more than 20 samples from the Waring Mountains (see plate 1 for location). The samples from the Nimiuk Point No. 1 are all Eocene to Pleistocene in age, while the samples from the Waring Mountains are all Cretaceous in age.

The geochemistry of the sediments in the Nimiuk Point No. 1 indicates that these rocks are immature and gas prone (table 1), and lack sufficient organic carbon to generate large quantities of hydrocarbons (table 2). A temperature gradient of 1.51 degree F/100 feet would imply that sediments in the well would only reach the oil window in the deeper parts of Selawik Basin to the west of the refuge (Larson and Olson, 1984).

The low level of organic carbon content, the nature of the kerogen, and the moderate geothermal gradient, coupled with the low level of thermal maturation of the sediments in the Nimiuk Point No.1, indicate that it is unlikely that significant amounts of hydrocarbons have been generated by these sediments. Should hydrocarbons occur, dry gas would be the most likely discovery.

It should be noted, however, that normally gas prone kerogens and possibly even coal have produced economical amounts of petroleum at relatively low level of thermal maturity (Larson and Olson, 1984)

The geochemistry of the sediments from the Waring Mountain range indicate that those sediments are overmature and are outside the oil and wet gas windows (table 3). The total organic carbon from these samples is an order of magnatitude below that from hydrocarbon rich basins.

The low level of organic carbon content and the high thermal maturation of the sediments on the Waring Mountains, indicate that it is unlikely that significant amounts of hydrocarbons are present in these sediments. Any oil that was once there would have most likely been broken down into gas or driven off during one of the deformations the rocks have undergone. Should gydrocarbons remain, dry gas would be the most likely discovery.

Table 1

Thermal Maturation and Visual Kerogen Analyses
Standard Oil of California nimiuk Pt. No. 1, (ADMGGS, 1986)

DEPTH	LOW-GRAY Ro MEAN	% POP	HIGH-GRAY Ro MEAN	% POP	TAI	THERMAL MATURITY	KEROGEN TYPE	HYDROCARBON POTENTIAL/REMARKS
100'	0.19	18	0.36	37		Immature	Cellulosic	Gas type kerogen
460'	0.23	65	0.69	33		Immature	Cellulosic	Gas type kerogen
820'	0.25	85	1.64	15		Immature	Cellulosic	Gas type kerogen
1180'	0.28	36	0.58	37	2	Immature	Cellulosic	Gas type kerogen
1540'	0.25	69	0.99	31	2	Immature	Cellulosic	Gas type kerogen
1900'	0.25	74	1.10	26	1+	Immature	Cellulosic	Gas type kerogen
2260'	0.34	85	1.75	15		Immature	Cellulosic	Gas type kerogen
2530'	0.35	80	0.91	20		Immature	Cellulosic	Gas type kerogen
2890'	0.31	74	2.29	17		Immature	Cellulosic	Gas type kerogen
3250'	0.37	66	0.72	34		Immature	Cellulosic	Gas type kerogen
3650'	0.35	100	-	-		Immature	Cellulosic	Gas type kerogen
3970'	0.39	45	0.59	32		Immature	Cellulosic	Gas type kerogen
4330'	0.36	100	-	-		Immature	Cellulosic	Gas type kerogen
4690'	0.37	72	1.36	25		Immature	Cellulosic	Gas type kerogen
5050'	0.41	47	0.74	38		Immature	Cellulosic	Gas type kerogen
5410'	0.44	85	0.87	15	2	Immature	Cellulosic	Gas type kerogen
5770'	0.51	68	1.03	32	2,2+	Immature	Cellulosic	Gas type kerogen
6130'	-	-	-	-		-	-	Metamorphic rocks
6250'	-	-	-	-		-	-	Metamorphic rocks

Table 2

Total organic carbon data from the Standard Oil of California Nimiuk Point No. 1, (Page, M.M., 1981, unpublished, in ADMGGS, 1986)

TOTAL ORGANIC CARBON DATA
STANDARD OIL OF CALIFORNIA NIMIUK PT. NO. 1

Sample Interval	Depth (feet)	TOC (PERCENT)
100- 220	160	0.19
730- 850	790	1.61
1360-1480	1420	8.34
1990-2110	2050	0.31
2620-2740	2680	1.11
3250-3370	3310	0.57
3880-4000	3940	0.14
4510-4630	4570	0.12
5140-5260	5200	0.06
5770-5890	5830	0.12
6211-6310	6261	0.18
	AVERAGE	1/16
	AVERAGE LESS 8.34 (high value)	0.44

Table 3

Thermal alteration index (TAI), total petroleum hydrocarbons (TPH) and equivalent vitrinite reflectance (EVF) data for Cretaceous rocks from the Waring Mountains (ADMGGS, 1986).

SAMPLE NO.	TPH (PERCENT)	TAI	EVF (PERCENT)
WL85-30	.00041		
WL85-32	.00190		
DT85-1	.00320		
DT85-2		3+ TO 4-	2.0 TO 2.5
DT85-3	.00140		
DT85-4			
DT85-5	.00030		
DT85-6		3+	2.0
DT85-7	.00014		
DT85-8		3+ TO 4-	2.0 TO 2.5
DT85-9	.00190		
DT85-10		3+ TO 4-	2.0 TO 2.5
DT85-11	.00160		
DT85-12		3+	2.0
DT85-13	.00170		
DT85-14		3+ TO 4-	2.0 TO 2.5
DT85-15	.00140		
DT85-16		3+ TO 4-	2.0 TO 2.5
DT85-17	.00160		
DT85-18		3+ TO 4-	2.0 TO 2.5
DT85-19		3+ TO 4-	2.0 TO 2.5

DESCRIPTION OF OIL AND GAS RESOURCES

Known Oil and Gas Fields (Regional)

Alaska has two oil and gas production areas. One is the Cook Inlet Basin, and the other is the Arctic North Slope. Neither of these areas is related to the Selawik NWR and, therefore, they are not discussed.

Known Oil and Gas Fields (Local)

There are no known oil and gas fields in Selawik NWR or the surrounding area.

Three unconfirmed oil seeps have been reported in the vicinity of Allakaket on the Koyukuk River and another unconfirmed oil seep has been reported on the Noatak River (Miller, Payne, and Gryc, 1959).

Two oil seeps have been reported on the Seward Peninsula near Devil Mountain in the northern Coastal Plain. These have not been investigated by the USGS. One seep is reported to have been analyzed and to be a petroleum oil, while the other is listed as doubtful (Miller, Payne, and Gryc, 1959).

In 1950, a hole was drilled at Kotzebue to test for fresh water. At 238 feet, gas under high pressure lifted the heave string of tools several feet in the air, showered the area with mud, and continued to flow for more than 24 hours. The gas may have been biogenic methane, from decaying organic matter (Miller, Payne, and Gryc, 1959).

Standard Oil Company of California drilled the Nimiuk Point Number 1 (T. 16 N., R. 16 W., Section 34, Kateel River Meridian) southeast of Kotzebue to a depth of 6,311 feet in 1974. This is the only oil and gas test well that is relatively close to the Selawik NWR. It was plugged and abandoned in 1975 as a dry hole. There was <u>no</u> indication of oil in the well. A formation test was run at 3,537 to 3,755 feet and a short blow was observed, but no gas was observed at the surface; therefore, this test must be classified as inconclusive. In addition, geophysical well logs indicated that gas may be present from 1,130 to 1,132 feet and from 1,158 to 1,160 feet. These zones would be too thin and too shallow to hold large quantities of gas, if they in fact do contain gas.

POTENTIAL FOR OIL AND GAS OCCURRENCE

Oil and Gas Occurrence Potential

Selawik NWR can be divided into three areas of oil and gas occurrence potential (oil and gas, collectively, will be referred to as hydrocarbons). These areas are shown in plate 2. There are two areas of moderate hydrocarbon occurrence potential, and the remainder of the refuge has a low hydrocarbon occurrence potential. The areas of moderate hydrocarbon occurrence potential are moderate for gas and have a low potential for oil, as does the remainder of the refuge. Appendix B describes BLM's mineral classification system.

The larger area of moderate hydrocarbon occurrence potential (approximately 1,100,000 acres) corresponds to the Tertiary and Quaternary sediments in the Selawik Basin. This area has a BLM hydrocarbon occurrence potential classification of M/C. This classification is based on the fact that the area is known to contain sediments that may provide a source and reservoir for hydrocarbon accumulation, the presence of gas on the Baldwin Peninsula, and the gas prone kerogens present in the sediments of the Selawik Basin. The area is bounded by the limits of Selawik Basin and the refuge boundary.

The smaller area of moderate hydrocarbon occurrence potential (approximately 800,000 acres) corresponds to the Cretaceous sediments of the Kobuk trough. This area has a BLM hydrocarbon occurrence potential classification of M/A.

This classification is based on the fact that the sediments in this area are overmature for oil and the complex faulting of these rocks along with their impermeable nature (Gates et al, 1968) imply that little gas would accumulate. This area is bounded by the Selawik Basin, the refuge boundary, and the limits of Cretaceous rocks as shown on plate 1.

The remainder of the refuge (approximately 1,300,000 acres) has a low hydrocarbon occurrence potential. This area has a BLM hydrocarbon occurrence potential classification of L/A. This classification is based on the fact that this area contains predominantly intrusive and extrusive igneous rocks. If the Koyukuk Terrane is in fact underlain by oceanic crust as indicated by the gravity map (figure 12) and the magnetic anomaly map, (figure 13), this area would probably have no hydrocarbon occurrence potential. Although the evidence most strongly supports this theory, there is some evidence to the contrary, and if the area is underlain by continental crust, there would be a small chance of an accumulation of hydrocarbons, again, most likely gas.

TYPICAL OIL AND GAS DEVELOPMENT SCENARIO

As mentioned in the geological assessment, the potential for discovering economical quantities of crude oil is low throughout the refuge. However, the assessment gave portions of the refuge moderate potential of finding economical natural gas reserves. Due to the location of this refuge and the estimated "most likely" gas reserves, the scenario presented assumes the market for this gas will be a local village or villages near the developed field. Should a large oil or gas field be discovered in this area, a pipeline could feasibly be built in an easterly direction to connect with the Trans-Alaska Pipeline System or the proposed Trans-Alaska Gas System or the produced products could be piped to the coast and barged to market. Obviously, the infrastructure needed to produce a major field this size would be more complex than the scenario described here.

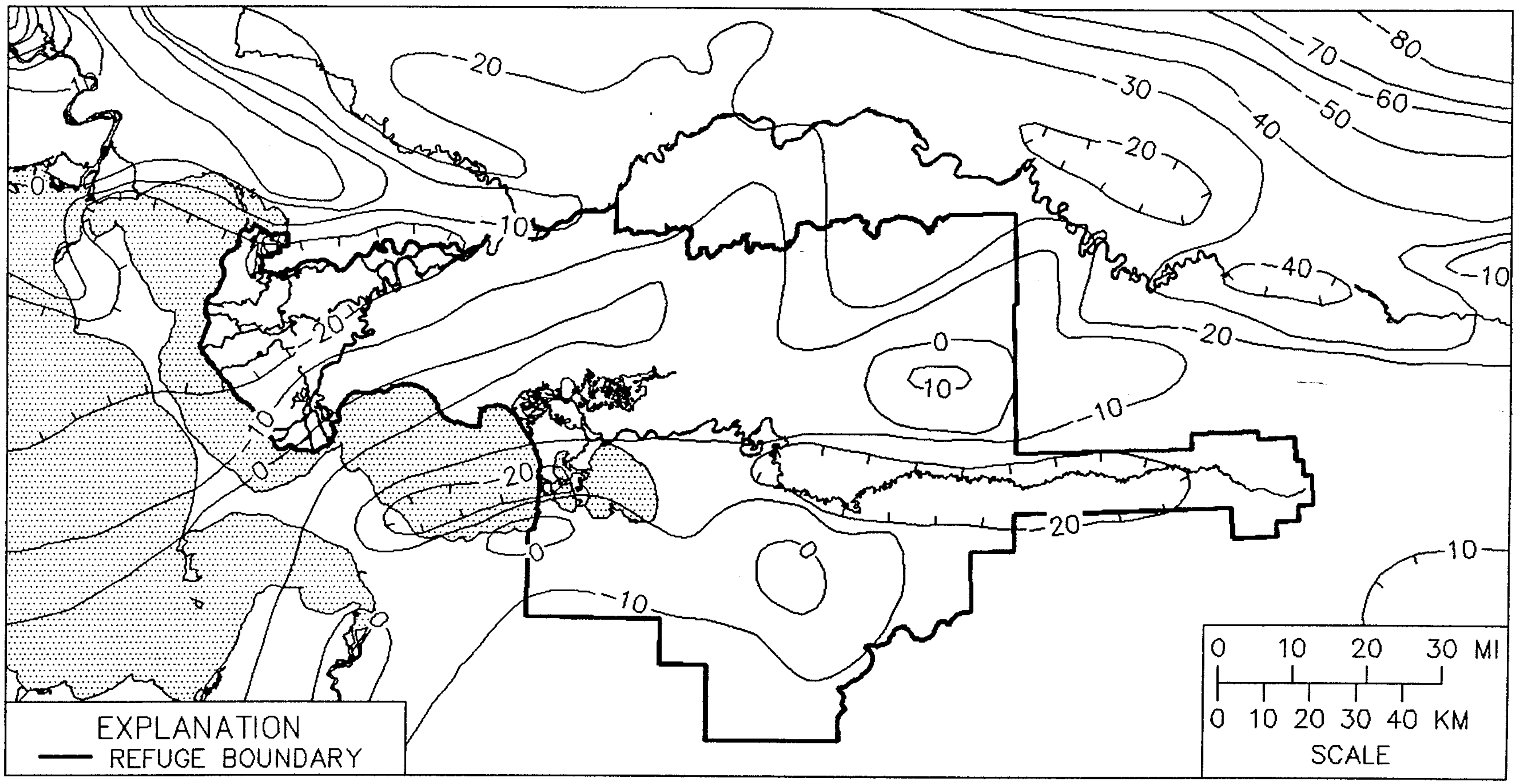

Figure 12. Bouguer gravity map of Selawik NWR (from Barnes, 1977).
(contour interval = 10 milligals)

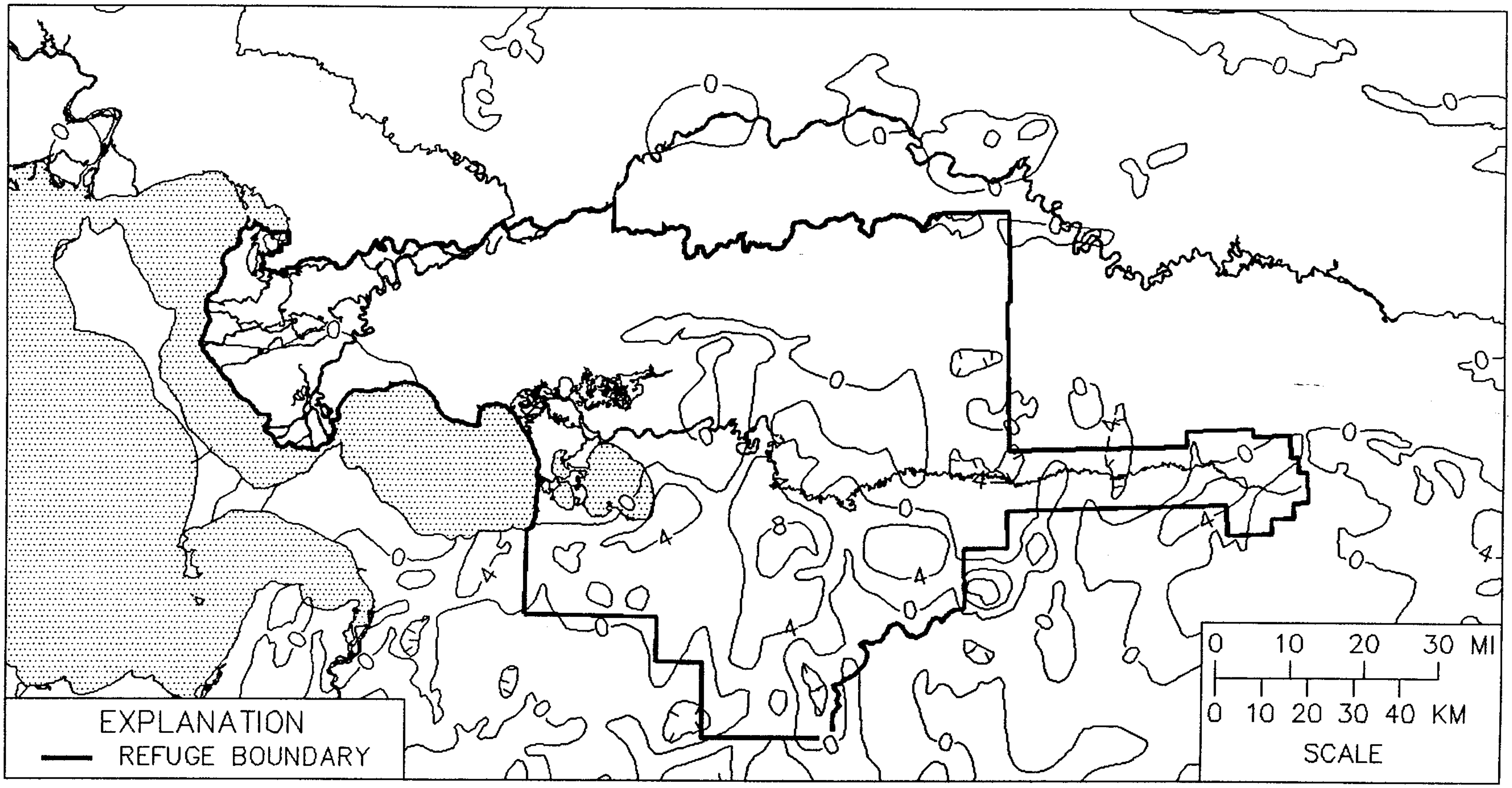

Figure 13. Simplified magnetic anomaly map of Selawik NWR (after Godson, 1984).
(contour interval = 400 gammas / contour labels times 100)

The following scenario was developed under these assumptions: The three- to six-inch production pipeline would be buried, there would not be a road connecting the field to existing road insfrastructure, all equipment, facilities, and supplies needed to develop and produce the gas would be transported overland to the field during the winter months, field personnel would be transported to and from the field by small aircraft, and domestic water would be taken from local sources.

In the event of an economic discovery in the SWR, development and production activities would begin on a year-round basis. Proposed plans for the production and transportation facilities are developed during the economic study of the discovery and submitted to local, State, and Federal agencies for approval. After completing the required review process, the plans are either approved or denied pending further information, studies, and/or modifications. Once approved, construction of the permanent pad, air support facility, and roads could begin. The first activity is to establish a temporary camp for the construction workers. As the pad and road infrastructure nears completion, the necessary wells could be drilled, the pipelines buried, and the needed production facilities and camp modules transported to the field and assembled. The modules would be designed to last the life of the field. Considering the likelihood of gas production and the potential market(s), one would expect this hypothetical field to produce 15 to 20 years.

For illustrative purposes, figure 14 shows the location of the facilities needed to produce our hypothetical prospect. Table 4 summarizes the acreage disturbed and gravel requirements for each facility, and table 5 is a summary of total acres disturbed and gravel required to develop this prospect. The drilling/production pad used in this scenario is designed to produce the entire prospect. Depending upon actual reservoir characteristics, more pads may be required to adequately deplete the resources. Once the gas is depleted from the prospect, the wells would be plugged, the facilities removed, and the disturbed surface reclaimed per Federal and State regulations.

Production Facilities

As shown, the facilities needed for the production of oil and gas are the central production facility, drilling/production pad, airstrip, pipelines, and roads.

Central Production Facility (CPF)

The CPF is the headquarters and primary operations center for the production activities of the field. Buildings on this pad would enclose the production equipment, housing needs, and office space. Areal extent of this pad is approximately 15 acres. To protect any permafrost from thermal degradation, it is estimated this pad will need to be at least five feet thick and, in addition, may require other insulating medium. Before construction

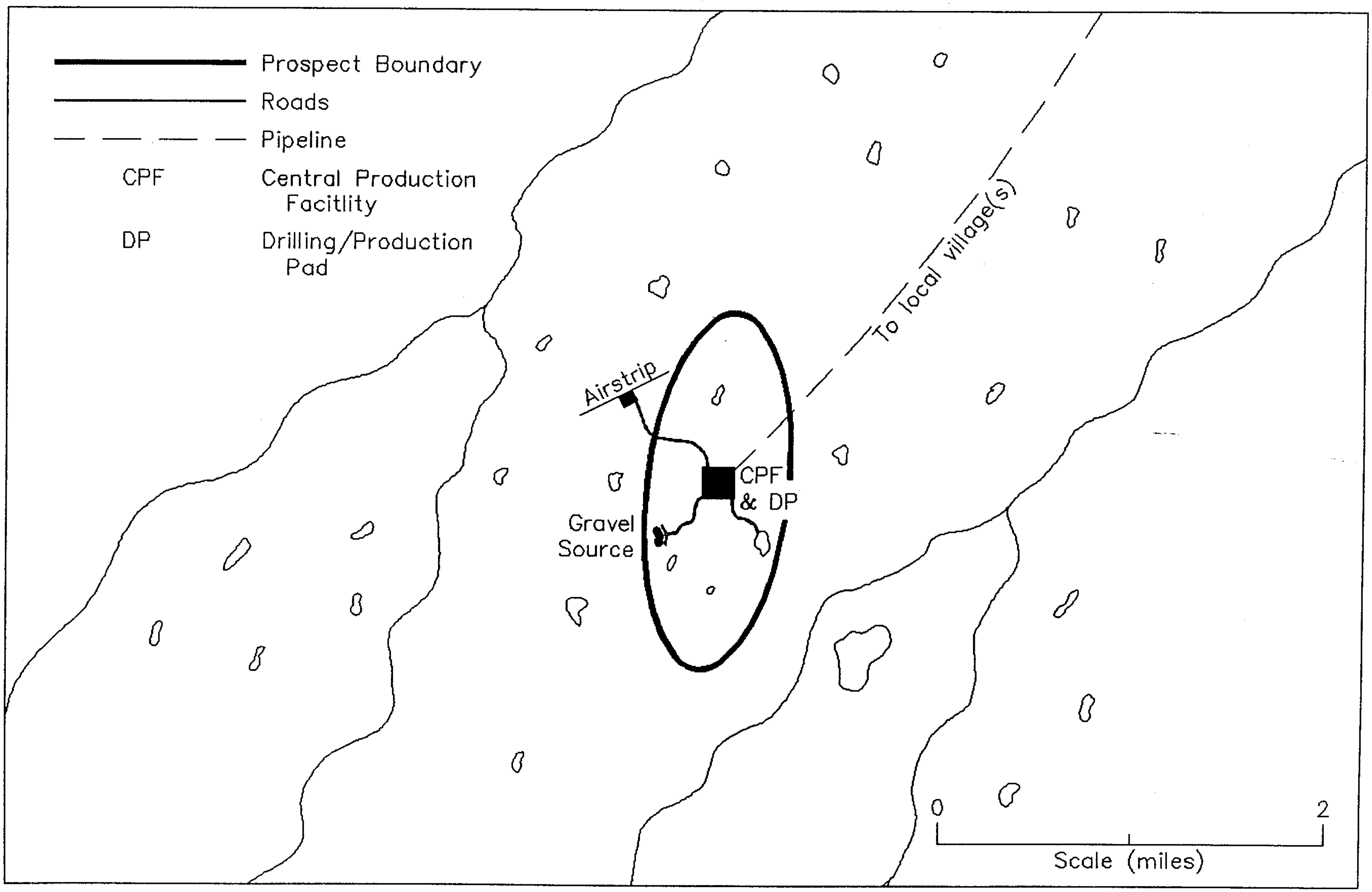

Figure 14. Development scenario for a hypothetical prospect, Selawik NWR.

Table 4

Production Facilities
Selawik NWR

Facility	Acres Disturbed (each)	Cubic Yards of Gravel to Construct (each)
Central Production Facility Pad & Drilling/Production Pad	15	120,000
Airstrip and Facilities	8-10	65,000-80,000
Roads	4 acres/mile	35,000 yd^3/mile

Table 5

TOTAL ACRES DISTURBED AND TOTAL GRAVEL REQUIREMENT FOR THE DEVELOPMENT OF THE SELAWIK NWR HYPOTHETICAL PROSPECT

Facility	Acres Disturbed	Cubic Yards of Gravel to Construct
Central Production Facility Pad & Drilling/Production Pad (1)	15	120,000
Airstrip and Facilities (1)	9	73,000
Roads (1.5 miles)	6	52,500
TOTALS:	30	245,500

began, detailed studies of the area would be performed to determine the most effective and economical construction design to protect the permafrost and the environment. Assuming a five-foot thickness and a 15-acre pad, approximately 120,000 cubic yards of gravel would be required.

A housing module would include sleeping and eating quarters, food storage area, and recreational and sanitation facilities. The module would be designed to accommodate 2 to 5 workers. The office module and shop would provide the necessary support services to develop and produce the field.

The production module would house a separator unit, compressor unit, and a gas cooling unit. Produced gas would be dehydrated, compressed, cooled, and sent down the production pipeline. Any produced water would be disposed down an injection well.

Water for domestic use would be obtained from rivers, local lakes, or water-filled pits (abandoned gravel source areas). Insulated tanks would store a sufficient amount of potable water for human consumption. Sewage treatment facilities and the incinerator would eliminate most of the human waste and trash. Items which could not be burned would be adequately stored and transported to an approved disposal site during the winter months.

Fuel storage would hold diesel and other refined petroleum products necessary for operating the equipment of the CPF. The area would be diked to contain any spills which may occur. Electricity would be provided by a natural gas powered generation plant.

Drilling/Production Pads

A drilling rig and necessary equipment and supplies for drilling the wells would be placed on the drilling/production pad. As wells are completed, wellheads and pipelines would be put in place. The size of these pads are dependent upon the number of wells drilled and the distance between wellheads. The presented scenario shows the CPF and drilling/production pad as one. For this hypothetical prospect, a 15-acre pad would be large enough to support the CPF modules and the 3-4 wells needed to produce the field.

Depending upon the proposed depth and subsurface conditions, production wells will take 10-60 days to drill and complete. Production from each well is piped to the CPF.

Production wells are directionally drilled from the pads to various bottom hole locations within the hydrocarbon reservoir. The procedure allows maximum depletion of the reservoir and minimizes the surface acreage disturbed. Spent drilling fluids would be injected into the subsurface and the solids, if environmentally sound, would be capped in the reserve pits. If the pits cannot be secured, the material would be transported to an approved disposal site during the winter months.

Airstrip, Roads, and Pipelines

The airstrip would be permanent and maintained year-round for the lifetime of the project. It is assumed the facility would be designed for small aircraft transporting personnel to and from the field. Minimum length of the airstrip would be 2,600 feet and minimum width would be 50 feet. Three acres of surface would be covered by the airstrip itself and another 5-7 acres are required for the taxiway, apron, and support facilities. Approximately 73,000 cubic yards of gravel would be required to construct this facility. If a larger field is discovered, an airstrip 6,000 feet long and 150 feet wide would most likely be built to accommodate all types of fixed-wing aircraft and helicopters.

Roads will connect all of the above facilities. They will be built with a crown width of 35 feet and would be approximately five feet thick. Each mile of road would cover four acres of surface and require 35,000 cubic yards of gravel. Total mileage varies between projects, depending on the size and surface features of the prospects.

Gathering lines would run from each well to the CPF. These lines would most likely be buried along the most direct route. Diameter of the pipe, for this hypothetical prospect, would be two or three inches.

The main production pipeline leaving the field would probably be three to six inches in diameter. The route of the buried pipeline to market will depend on circumstances at the time production begins. This scenario assumes a nearby village would be interested in purchasing natural gas for their local needs. If an interested village is located near the gas discovery, a road connecting the village to the field infrastructure may be economically built. This would eliminate the need for housing and office modules on the CPF pad, which would decrease the size of this pad to 5-7 acres.

ECONOMIC POTENTIAL

Background

The Selawik Refuge is located approximately 280 miles northwest of Fairbanks and is south and adjacent to the Kobuk Valley National Park (figure 1). The refuge was created in 1980 upon passage of the Alaska National Interest Lands Conservation Act (ANILCA) and encompasses approximately 3.2 million acres (5,000 square miles). Approximately two-thirds of the land is under Federal jurisdiction and, of the balance, most has been selected or conveyed to Native Corporations. The refuge is accessible by airlines, air taxi, barge, and boat transportation. There are no roads on the refuge other than a few gravel covered roads in towns for local access.

Summary of Exploratory History

Presently, oil and gas leasing is prohibited on the refuge due to its wildlife status. Subject to site-specific compatibility with refuge purposes, oil and gas exploration inclusive of seismic activities may be allowed. There are no known oil and/or gas fields either on the refuge or in the surrounding area.

To date, drilling for oil and gas has not occurred within the boundaries of the refuge. Standard Oil Company of California drilled the Nimiuk Point Number 1 well, southeast of Kotzebue, approximately five miles west of the refuge, in 1974. This is the only oil and gas test well that is relatively close to the refuge. This well proved unsuccessful and after penetrating to 6,311 feet, it was plugged and abandoned the following year. There was no indication of oil in the well. A formation test was run at 3,537-3,755 feet and a short blow was observed, but no gas was observed at the surface; therefore, this test must be classified as inconclusive. In addition, geophysical well logs indicated that gas may be present from 1,130-1,132 feet and from 1,158-1,160 feet. These zones would be too thin to hold economic quantities of gas, if they in fact do contain gas.

In 1950, a hole was drilled at Kotzebue to test for fresh water. At 238 feet, gas under high pressure lifted the heavy string of tools several feet in the air, showered the area with mud, and continued to flow for more than 24 hours. The gas may have been biogenic, formed from decaying organic matter. Oil seeps have been reported on the refuge and in the adjacent Seward Peninsula over the years, but these findings have either not been investigated by the USGS or, if investigated, have not been confirmed.

Summary of Geologic Potential

The geologic petroleum potential[1/] of the Kenai Refuge has been evaluated by this office based on available geological and geophysical information. Based on guidelines found in the BLM Manual, Section 3031 (see appendix B), the whole of the refuge was determined to have either a low or moderate potential for the accumulation of gas resources and a low potential for oil. As can be seen in plate 2, the areas of moderate potential for gas occur in the Northern and Central portions of the refuge and occupy almost 60 percent of the land area. The balance of the refuge along the eastern and southern borders have been determined to be in an area of low potential for both oil and gas and occupy an area of just over 2,000 sq. miles.

1/ Geologic petroleum potential refers only to the probability of the presence (occurrence) of a concentration of that mineral resource. It neither refers to or implies potential for extraction or that the concentration of the resource, if any, is economic or could be extracted profitably.

The above subjective determinations are based mostly on geochemistry as well as findings from the drilling of the Nimiuk Point Number 1, and the test hole drilled at Kotzebue in 1950. For a more detailed discussion on the basis of these findings, please refer back to the three sections of this report which are entitled Geochemistry, Description of Oil and Gas Resources, and Potential for Oil and Gas Occurrence.

In classifying the mineral potential for lands within the Selawik Refuge, the BLM Manual requires that a determination be made as to the reliability of the data used, based on the type and quantity of data available to make these judgmental calls. As can be seen in appendix B, there are four categories for data quantification, known as "Levels of Certainty." These Levels of Certainty are "A, B, C, and D," with "D" representing the highest Level of Certainty and data quantification, and "A" representing the lowest or least reliable category based on the amount of data and type of evidence to make a decision.

For the subject Selawik Refuge, the Level of Certainty for the area of low potential, as well as the area of moderate potential for gas in the northern area of the refuge was determined to be "A." The definition for this lowest Level of Certainty/reliability is: "The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area."

For the area of moderate potential for gas, which is located in the central portion of the refuge, the Level of Certainty determined to be the most apropos was "C." The definition for this level is defined as follows: "The available data provide direct evidence, but are quantitatively minimal to support or refute the possible existence of mineral resources."

Development Potential

The development or economic potential of an area considers not only the geologic environment concerning the existence of mineral resources, but also the nongeologic environment.

The nongeologic environment includes such considerations as market availability, the existing infrastructure in the subject area, price projections, costs of production and marketing, anticipated rate of return, and also alternative investment opportunities.

The Selawik Refuge has been determined to be an area of "Low" economic and developmental potential for oil and gas resources. By this is meant that it is very unlikely that the area will be further explored and developed within the next 25 years. As previously indicated, no drilling has occurred on the refuge to date, and the scant information that is available is not very promising for the occurrence of gas within the refuge; for oil the possibilities are even lower. Over the years, industry has shown little, if any, interest in the area, and this is not expected to change in the foreseeable future.

In conjunction with the above facts, the physical remoteness of the area, lack of infrastructure inclusive of the nonexistence of roads, would result in industry incurring high capital costs to explore and develop this area. The closest existing production to this refuge is in the Prudhoe Bay Field, 250 miles northeast of the refuge, or in the Kenai Peninsula Field, approximately 450 miles to the southeast. It is expected that industry, in ranking this area against other investment opportunities, would be strongly inclined to focus their interest on areas showing greater promise.

Current technology exists that would allow exploration and development of potential hydrocarbon resources from this refuge, should commercial quantities be discovered; so the interest in opening this area to exploration is dictated by the resource potential and economic viability of oil and gas development in the area.

Price Projections

Current petroleum price projection compiled from a variety of sources[2/] are significantly lower than previous forecasts completed earlier in the 1980s (appendix C, table 1). The range of oil prices projected in these current forecasts vary from $18 to $42 per barrel by the year 2000 (constant 1984/85 dollars). With such a wide spread in forecasts, it is difficult to assess future impacts of this variable of future exploration activities. It was of interest to note that both a private research firm and a major oil company forecast a crude oil price of $35/barrel, whereas the most optimistic level of $42/barrel was a forecast of the U.S. Department of Energy (DOE) and was dependent on high economic growth. Assuming that high economic growth is not achieved, the DOE mid-range forecast of $36.75 is less than $2/barrel higher than those of the private sector. This level ($36.75/barrel by the year 2000) is approximately $5/barrel, or 12 percent, less than the average annual refiner's cost of imported crude in 1981/82 (constant 1984 dollars). This scenario does reflect an optimistic picture as compared to the current pricing structure.

Other forecasts from the same sources indicate an upward trend in petroleum demand, but conversely project a decline in domestic production which is indicative of a decrease in domestic exploration activities.

One last petroleum price projection that should be considered is the scenario presented by Arlon Tussing, a Seattle based energy economist. Mr. Tussing, in late 1980, against all conventional price projections, correctly forecast that international oil prices would soon collapse. In January 1984, prior to the concern of most energy forecasters, he stated that we were headed for a 10-year cycle of falling prices, and he projected that oil would soon drop within the range of $12 to $20 per barrel. To date, this forecast has been quite accurate.

[2/] U.S. Department of Energy, 1985; Data Resources Incorporated, 1986; Chevron Corporation, 1986.

Mr. Tussing's latest forecast is even more foreboding, as he expects oil prices in constant dollars to remain within a range of $10 to $20 a barrel through the rest of the century. Beyond this timeframe, he expects energy prices to decline even further.

The basis for this scenario is "fuel switching." Mr. Tussing states that "many" of the industrial users are now equipped to use alternate fuels such as oil, gas, or coal, depending on the prevailing price. He believes that the exceptional high prices during the six-year period between 1979 and 1985 were possible only because heavy industrial users were not at that time equipped to switch fuels and were heavily dependent on oil as a bulk fuel. This stemmed from the fact that exceptionally low oil prices prevailed in the 1950s and 1960s, and this trend was expected to continue ad-infinitum. He points out that for a century, between 1878 and 1978, crude oil prices never exceeded $15/barrel in 1986 dollars, and the average wellhead price during this 100-year period was between $8 and $9/barrel. Mr. Tussing believes that as long as technological progress is self-sustaining, the long-term price trend for oil can only be downward.

The wide divergence in oil price projections just presented are indicative of the future uncertainty which exists in the national petroleum industry. As we have seen, though, most mainline economists are forecasting an upward trend in long-term bulk oil prices. Although this is considered a promising sign for the industry as a whole, this if foreshadowed by forecasts of a long-term decline in U.S. production. This decline was brought on by a general cutback in drilling and production activities by U.S. petroleum companies triggered by an excess world supply and resultant low product prices. Future expansionary efforts by the petroleum industry would be anticipated to take place in areas where, hopefully, capital costs can be held down, or, in lieu of this, in areas of great promise.

Overview

In 1985, Alaska contributed nearly 20 percent of domestic petroleum production (United States Department of Energy, Energy Information Administration, 1986). In comparison, Alaska is a relatively minor producer of natural gas, with production of approximately 300 billion cubic feet per year in 1985 (United States Department of Energy, Energy Information Administration, 1986a). However, Alaska is an exporter of natural gas in the form of liquified natural gas (LNG), which is primarily shipped to Japan.

Fundamental changes in the petroleum industry since the early 1970s will certainly be a force in shaping the industries' future. This period brought two major crude oil price shocks, rapid expansion in petroleum demand and heavy reliance of foreign sources of supply to meet domestic needs. Similarly, the consumer experienced shortages in natural gas supply which resulted in a new era of gas price regulation (see appendix C for a detailed discussion of these changes). The rapid growth of the energy sector in the late 1970s and early 1980s resulted in the highest petroleum prices ever experienced by the industry. This set the stage for a period of energy conservation efforts, followed by declining demand and excess world productive capacity with falling petroleum prices. By the middle of 1986, crude oil prices had dropped to levels at or below prices received in 1973, before the Arab oil embargo. Natural gas price increases stimulated drilling and production in the early 1980s, which has resulted in domestic surplus capacity (gas bubble) and depressed prices. The present unstable nature of the oil and gas industry has resulted in a great deal of restructuring within the industry and expectations for the future are very uncertain.

Most recent long-term price forecasts project an upward trend that will be realized in the 1990s and possibly beyond (see appendix C for specific prices and trends). Domestic petroleum demand is expected to rise slightly above the 1985 level of 15.7 million barrels per day to a range from 15.9 to 18.1 million barrels per day by the year 2000. Natural gas demand could also increase from 17.4 trillion cubic feet per year in 1985 to a possible range from 17.1 to 20.4 trillion cubic feet per year in the year 2000. In contrast, domestic production of petroleum and natural gas is projected to decline below 1985 levels by the year 2000 (see appendix C for a more detailed discussion of historic and future petroleum and natural gas demand sand supply relationships). Therefore, the United States' dependency on foreign sources of hydrocarbon supplies is expected to increase above current levels. Based on these projections, there is a considerable gap between domestic consumption and production that can only be filled nationally by exploring new areas and developing any commercial discoveries that are made.

In summary, if the Selawik Refuge were opened to oil and gas exploration and development, some benefits would accrue to the local economy through the expenditure of explorational dollars, with some small-scale benefits to the State. Economic benefits would, of course, be dependent on industries' interest in the area and investing the necessary capital for development. Presently, and at least through the turn of the century, it is expected that industry will not have significant interest in the area and, as such, would be more inclined to expend their exploration dollars in areas of greater promise. Any long-term benefits that would accrue would, of course, be dependent on locating commercial quantities of oil and gas that could be recovered from a favorable economic viewpoint.

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APPENDIX A

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
FISH AND WILDLIFE SERVICE
AND THE
BUREAU OF LAND MANAGEMENT
U.S. DEPARTMENT OF THE INTERIOR

BACKGROUND:

Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA) requires the Secretary of the Interior to initiate an oil and gas leasing program on the Federal lands of Alaska; it exempts, ". . . those units of the National Wildlife Refuge System where the Secretary determines, after having considered the national interest in producing oil and gas would be incompatible with the purpose for which such unit was established." Section 1008 also madates that:

> "In such areas as the Secretary deems favorable for the discovery of oil or gas, he shall conduct a study, or studies, or collect and analyze information obtained by permittees authorized to conduct studies under this section, of the oil and gas potential of such lands and those environmental characteristics and wildlife resources which would be affected by the exploration for and development of such oil and gas."

Section 304(g) of ANILCA requires that the Secretary of the Interior prepare a "comprehensive conservation plan" for each of the 16 National Wildlife Refuges in the State of Alaska. Among other things, these plans are to ". . . specify the uses within each such area which may be compatible with the major purposes of the refuge." The U.S. Fish and Wildlife Service (FWS) has the responsibility for preparing the refuge comprehensive conservation plans and is using the refuge planning process to define those areas on refuges where oil and gas exploration and development may be compatible with the purposes for which each refuge was established.

PURPOSE:

To fully comply with Section 1008 of ANILCA (i.e., to consider the national interest in producing oil and gas from refuge lands), an accurate defensible oil and gas resource assessment should be prepared for each National Wildlife Refuge in Alaska. The FWS has limited technical expertise in assessing mineral potentials. However, this expertise does exist within the U.S. Bureau of Land Management (BLM). The purpose of this memorandum is to establish cooperative procedures between the FWS and the BLM for the mutual responsibility of assessing the oil and gas potential of National Wildlife Refuge lands in Alaska.

IT IS MUTUALLY AGREED THAT:

The BLM will develop an oil and gas resource assessment for each of the 16 National Wildlife Refuges in the State of Alaska. These assessments will consist of the following items (to the extent that available data permits):

1. A detailed narrative discussion of the geologic character of the refuge.

2. A map showing all known geologic formations and geologic features pertinent to the mineral assessment.

3. A geologic cross section showing the subsurface character of the study area.

4. A detailed discussion of the engineering aspects, if there is a potential for development in the area, including the types of facilities and the infrastructure necessary to economically develop the hydrocarbon potential.

5. A generic development scenario map that will graphically portray the facilities and infrastructure discussed in item 4 above.

6. An economic assessment that will include:

    a. a brief overview of the national energy situation and discussion of the importance of Alaskan oil and gas production;
    b. a generalized discussion of the economic potential for oil and gas production from the refuge being evaluated;
    c. a discussion of the factors that may affect future oil and gas development on the refuge.

The above six items shall be considered the minimum elements to be included in any refuge assessment. If sufficient nonproprietary geological and geophysical data exist, and the hydrocarbon resources warrant further description, some or all of the following items (time permitting) will also be included in the resource assessment:

a. structural contour maps showing the location and surface areas of potential mineral occurrences;
b. maps showing the magnetic and/or gravity character of the area;
c. maps showing the thickness of identified rock formations;
d. reservoir character map showing the porosity, water saturation, and permeability characteristics of potential reservoirs; and
e. a detailed development scenario map showing roads, docks, pipeline corridors, etc., required to develop the prospects.

In preparing the oil and gas resource assessments, the BLM shall make use of (1) existing literature, (2) geological and geophysical information and data collected from FWS lansd by industry permittees (see Memorandum of Understanding between FWS and BLM, dated August 1984 -- attachment 1), and (3) geological and geophysical information and data collected on or adjacent to FWS lands by the BLM, the U.S. Geological Survey, the State of Alaska, and other government agencies. during the evaluation process, BLM geologists will make official contacts with mineral companies that may have an interest in the area. These companies will be given an opportunity to submit data for consideration and they will also be given the opportunity to discuss their feeling on the study area and its oil and gas development potential with the evaluating geologists. All interactions will be documented and submitted to the Fish and Wildlife Service at the close of the project.

The oil and gas resource assessments prepared by BLM will be delivered to the FWS in form suitable for public release. These assessments will be public documents, and the FWS will make copies of the assessments available for public review. All formal communications with the public concerning the management of FWS lands (e.g., the opening of refuge lands to oil and gas exploration or development) will be the responsibility of the FWS.

In developing the oil and gas assessment, proprietary information that was obtained by the BLM will be shared with the FWS as support for statements made in the assessment; however, proprietary information will not be included in the public report.

The number of refuge resource assessments that BLM will complete each year and the amount of funding that FWS will provide to BLM will be determined on an annual basis by mutual agreement. The following three goals have been established to assist the FWS and the BLM in planning their work commitment for completing the refuge oil and gas assessments:

1. The Becharof, Alaska Peninsula, Yukon Flats, and Kenai National Wildlife Refuge oil and gas assessments will be completed during the 1986 fiscal year,

2. If at all possible, the oil and gas assessments for the remaining 12 refuges will be completed during the 1987 and 1988 fiscal years,

3. The FWS will reimburse the BLM for completion of oil and gas assessments, and FWS will prioritize the assessments to be completed each year, with consideration for concurrently conduction analyses, if possible, on refuges in similar geographic locations or of similar geologic character.

However, nothing in this MOU shall be construed as requiring either agency to assume or expend any funds in excess of appropriations available. The remaining 12 National Wildlife Refuge (NWR) resource assessments will be conducted in the priority order established by the FWS on an annual basis:

1.	Togiak NWR	7.	Innoko NWR
2.	Tetlin NWR	8.	Selawik NWR
3.	Kanuti NWR	9.	Kodiak NWR
4.	Yukon Delta NWR	10.	Alaska Maritime NWR
5.	Koyukuk NWR	11.	Izembek NWR
6.	Nowitna NWR	12.	Arctic NWR

Amendments to this agreement may be proposed by either party and shall become effective upon mutual approval. Meetings to discuss the MOU may be called by the FWS Regional Director or the BLM State Director.

/s/ Robert E. Gilmore
Regional Director
U.S. Fish and Wildlife Service

March 17, 1986
Date

/s/ Michael J. Penfold
State Director
Bureau of Land Management

02/26/86
Date

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
FISH AND WILDLIFE SERVICE
AND THE
BUREAU OF LAND MANAGEMENT
U.S. DEPARTMENT OF THE INTERIOR

ARTICLE 1 Background and Objectives

Jointly, the Fish and Wildlife Service (FWS) and the Bureau of Land Management (BLM) share responsibility to help meet Department of the Interior objectives in Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA) of December 1980. The FWS is authorized to issue permits for the study of oil and gas on national wildlife refuges; the BLM may analyze resulting data for identification of potential.

The FWS is issuing permits for surface geology on all refuges. Permits for geophysical exploration may be issued on refuges having approved Comprehensive Conservation Plans. Data from both activities are required to be furnished to the FWS.

This Memorandum of Understanding is entered into to initiate the role of BLM to accept such data from FWS and be responsible for its confidentiality.

ARTICLE 2 Statement of Work

The FWS agrees to deliver to BLM data collected from permittees of oil and gas studies provided for in Section 1008 of ANILCA. The BLM agrees to accept the data, store it, and keep it confidential.

ARTICLE 3 Term and Modification

This understanding shall continue from date of signature ten years hence. It may be modified and/or extended by mutual agreement, and terminated by either party with sixty days' notice.

/s/ Robert E. Putz — 08/08/84
Regional Director — Date
Fish and Wildlife Service

/s/ Michael J. Penfold — 08/27/84
State Director — Date
Bureau of Land Management

APPENDIX B

BLM'S MINERAL POTENTIAL CLASSIFICATION SYSTEM
(From BLM Manual, Chapter 3131)

Mineral Potential Classification System

I. Level of Potential

O. The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines or deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.

ND. Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

II. Level of Certainty

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within a respective area.

B. The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C. The available data provide direct evidence, but are quantitatively minimal to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

For the determination of No Potential, use O/D. This class shall be seldom used, and when used, it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholithic (igneous intrusive), one can conclude, with reasonable certainty, that the area does not have potential for coal.

As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and/or mineral resources. It does not refer to or imply potential for development and/or extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

APPENDIX C

Oil and Gas Demand and Supply Relationship

The importance of potential oil and gas resources from this refuge is dependent on the hydrocarbon potential of the area, national need for additional sources of oil and gas, and the economics of exploring and producing any hydrocarbons that might be discovered. This Appendix provides a detailed review of the factors that have contributed to the present domestic oil and gas situation and possible future demand for oil and gas, which is directly linked to the national need for oil and gas resources from the refuge.

Domestic Energy Trends

The domestic energy situation, as it relates to oil and gas consumption and production, has changed dramatically since the early 1970s. In 1970, petroleum and natural gas supplied 44 and 33 percent (United States Department of Energy, Energy Information Administration, 1984), respectively, of the total energy consumed in the United States (figure 1). By 1977, petroleum accounted for nearly 49 percent of domestic energy consumption, and natural gas consumption had declined to approximately 26 percent of total energy demands. The relative contribution of both petroleum and natural gas declined through 1985, when petroleum supplied nearly 42 percent, and natural gas contributed approximately 25 percent of total energy demand. Figure 1 shows the contribution of each major primary energy source to total national energy demand in 1970, 1980, and 1985. Coal, nuclear, and geothermal energy were the primary forms of energy to increase their market share of total energy consumption during this time period, at the expense of petroleum and natural gas resources.

Total domestic energy consumption peaked at 78.9 quadrillion (QUAD) British thermal units (BTU) in 1979 and subsequently declined to 73.8 QUADS in 1985 (United States Department of Energy, Energy Information Administration, 1986). Over the 15-year period from 1970 to 1985, total primary energy consumption increased 11 percent, from 66.4 QUADS to 73.8 QUADS; however, the rapid increase in energy consumption and escalation in the cost of energy (the cost of energy more than doubled, from 1.35 constant 1972 dollar per million BTU in 1970 to 2.90 in 1981) during this time period resulted in a dramatic change in national energy consumption patterns. Total energy consumed per constant 1972 dollar of Gross National Product (GNP) ranged from 56,500 to 61,000 BTUs per 1972 dollar of GNP from 1960 through 1976 (United States Department of Energy, Energy Information Administration, 1985a). A decline in the intensity of energy utilization was realized in 1977, when total energy consumption dropped to 55,700 BTUs per dollar of GNP, and this downward trend continued through 1985, when energy consumption was reduced to 42,900 BTUs per 1972 dollar of GNP (United States Department of Energy, Energy Information Administration, 1986). The decline in energy consumption was led by the

FIGURE 1
PRIMARY ENERGY CONSUMPTION BY SOURCE

FIGURE 1A
1970
Total = 65.4 Quadrillion Btu

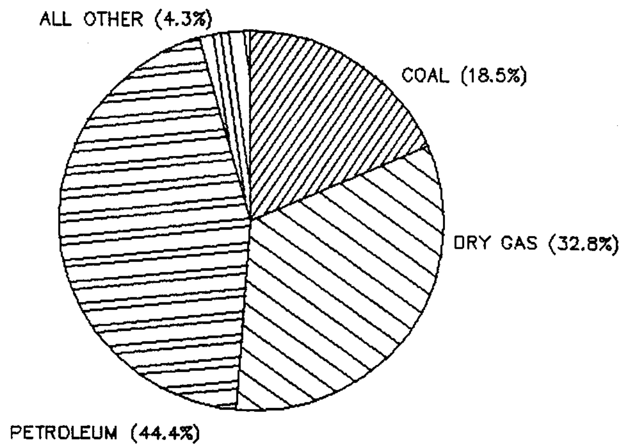


FIGURE 1B
1980
Total = 75 Quadrillion Btu

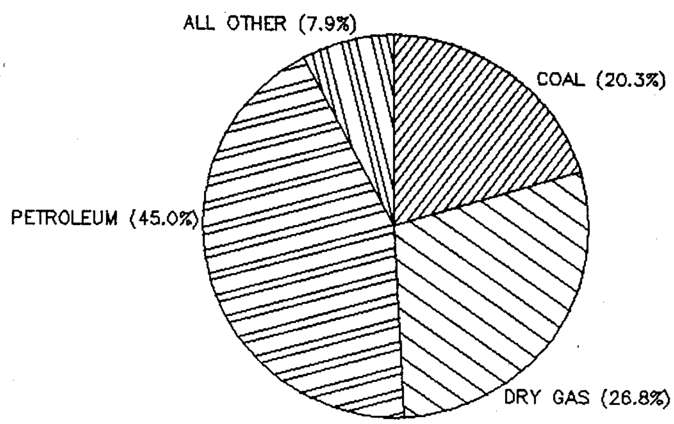
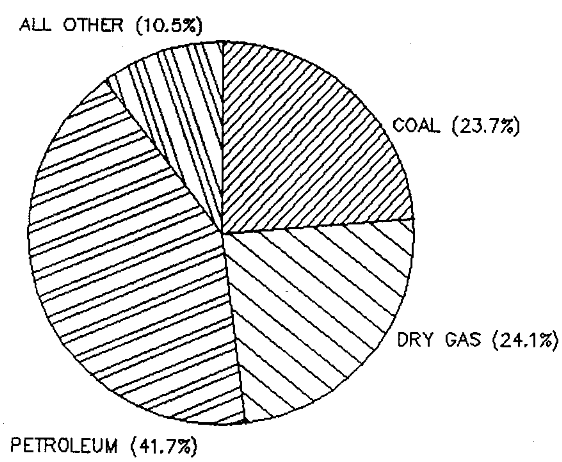


FIGURE 1C
1985
Total = 73.5 Quadrillion Btu



reduction in the intensity of petroleum and natural gas utilization. In 1985, only 68 percent as much petroleum and natural gas were consumed per dollar of GNP than in 1977, as compared to 77 percent for total energy consumption. The reduction in intensity of energy utilization was indicative of a national conservation effort which any be attributed to many factors, including: increased real energy prices, the increased service orientation of the economy, and changes in the mix of product production (United States Department of Energy, Energy Information Administration, 1985a).

Historical Oil and Gas Demand, Supply, and Price Relationships

The relationship between price and domestic petroleum supply and demand is shown in figures 2 and 3. Import prices utilized for petroleum in figure 3 are represented by the national average refiner's acquisition cost of imported crude oil, and wellhead prices are presented on the basis of the national average from all producing wells. Domestic crude oil prices were not completely decontrolled until January 1981 and, therefore, domestic wellhead prices do not follow import prices during the 1970s. Petroleum product demand rose throughout the early 1970s, until it peaked at 18.8 million barrels per day (MBPD) in 1978 (United States Department of Energy, Energy Information Administration, 1986a). Crude oil price increases began with the Arab oil embargo in 1973, and a second major price run-up was triggered in 1978 by the Iranian revolution and subsequent oil stock building in anticipation of world oil shortages. Real import prices peaked at $44.00 per barrel (1985 dollars) in 1980.

Domestic petroleum product demand began a downward slide in 1979 which continued through 1983. The Organization of Petroleum Exporting Countries (OPEC) members sought to maintain the higher prices, that resulted from oil price shocks of the 1970s, by production restraints. However, oil prices have steadily declined since 1981 as a result of slow economic growth with subsequent declining petroleum demand and excess world productive capacity (United States Department of Energy, Energy Information Administration, 1986b). Domestic oil prices in the second quarter of 1986 had declined to the lower teens in nominal terms, which is comparable to 1974 prices in real dollars. Figures 2 and 3 show that petroleum demand is sensitive to price and is characterized by long lags and high elasticities.

Domestic petroleum production has been much more stable than petroleum product demand. Figure 2 shows that Alaskan production, primarily from the North Slope, contributes a significant portion of domestic supply. In 1985, Alaska accounted for more than 20 percent of the national crude oil production (United States Department of Energy, Energy Information Administration, 1986a). Price increases of the 1970s provided incentive for exploration and production from higher cost areas such as Alaska. Foreign imports have been required to fill the gap between domestic supply and demand. Crude oil and petroleum product imports peaked in 1977, when net imports accounted for more

FIGURE 2
NATIONAL PETROLEUM DEMAND
AND SUPPLY 1970 - 1985

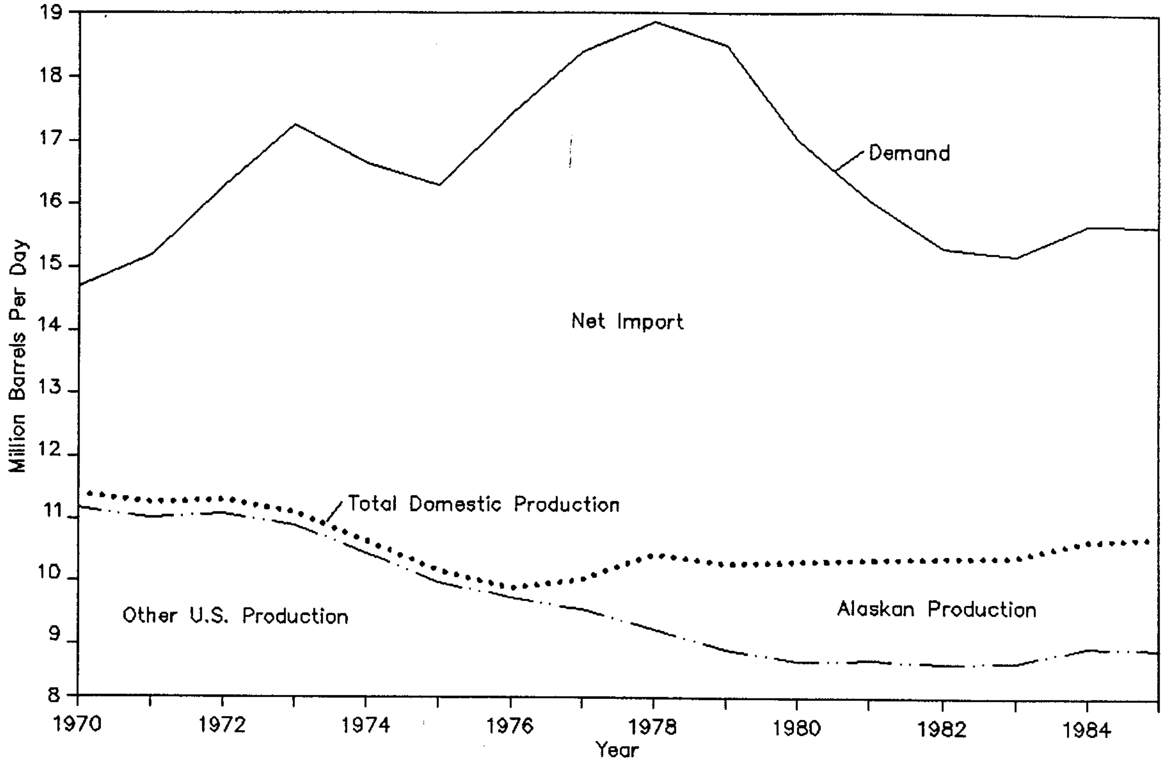
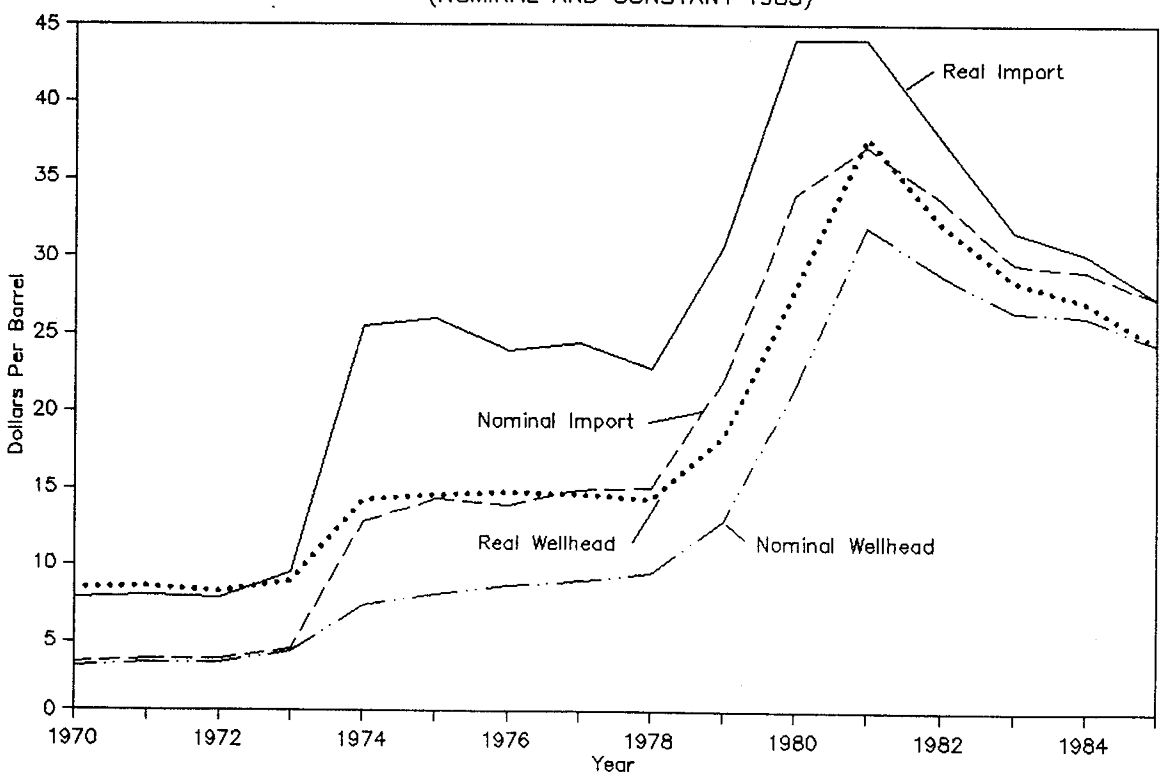


FIGURE 3
CRUDE OIL PRICES
(NOMINAL AND CONSTANT 1985)



than 46 percent of domestic petroleum consumption. Net petroleum import levels declined to 27 percent of product demand in 1985, but the United States still remains highly dependent of foreign petroleum supply sources.

The history of natural gas production and consumption in the United States is quite different from petroleum, and it has a direct bearing on gas pricing policies, demand, and supply relationships in the 1970s and 1980s (figures 4 and 5). Natural gas went from a little used waste by-product of oil production in the 1930s to a source of energy that supplied nearly 33 percent of national consumption in 1970 (figure 1). By 1970, gas was being delivered to consumers at prices well below those of competing petroleum products (United States Department of Energy, Energy Information Administration, 1984). Prices paid to gas producers by interstate pipeline companies were held at low levels through regulation by the Federal Power Commission, which resulted in increased demand and reduced incentives for producers to explore and develop new gas reserves. Regulated prices allowed intrastate transmission companies and distributors to bid natural gas supplies away from interstate carriers (Tussing and Barlow, 1984). The 1970s has been noted for the gas supply shortages in the midwest and northern states. Imported gas prices increased in a pattern similar to oil prices, but domestic prices remained under regulation. The Natural Gas Policy Act was passed in 1978, which allowed wellhead prices to increase and it deregulated certain categories of gas. Price increases provided incentives to explore and develop new sources of gas. Natural gas consumption started a sharp decline after 1980 under the influence of higher gas prices, a weak economy, warm winters, and, since 1981, falling oil prices (United States Department of Energy, Energy Information Administration, 1984). This trend continued through 1985, with the exception of a small increase in gas demand realized in 1981, which may be attributed to the strong economic growth in the national economy in that year.

Net imports of natural gas are primarily received through pipelines from Canada and Mexico, although there are some liquified natural gas (LNG) imports from Algeria. Net imports generally ranged near five percent from 1970 to 1985. Alaska is a relatively small producer of natural gas, ranging from approximately 100 to 325 billion cubic feet per year from 1970 to 1985 (United States Department of Energy, Energy Information Administration, 1985b).. Alaska is, however, a net exporter of natural gas in the form of LNG, which is delivered to Japan. Huge gas reserves have been identified on the Alaskan North Slope, but this resource has not been commercially produced due to a lack of transportation infrastructure.

Future Oil and Gas Demand, Supply, and Price Relationships

From the review of historic petroleum and natural gas price, demand, and supply relationships, it is apparent that there have been fundamental changes, such as petroleum price deregulation and energy conservation efforts in the national energy market since the early 1970s that will likely affect future

FIGURE 4
NATIONAL NATURAL GAS DEMAND
AND SUPPLY 1970 – 1985

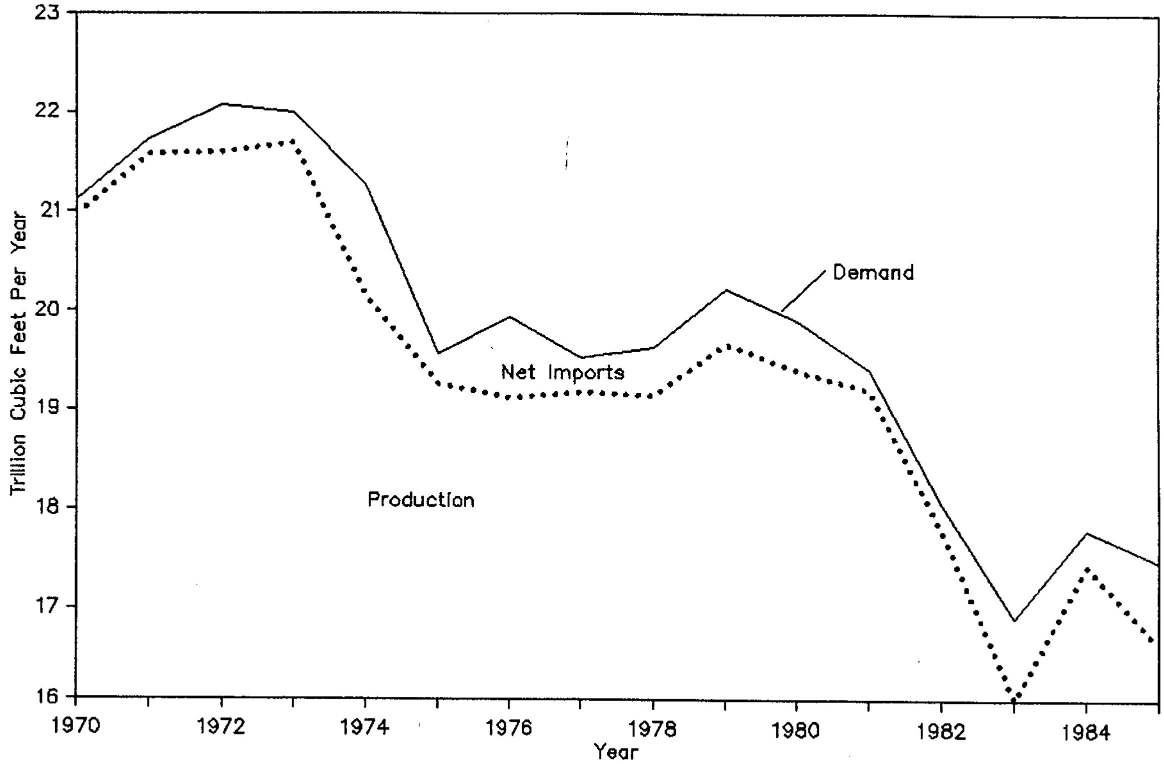
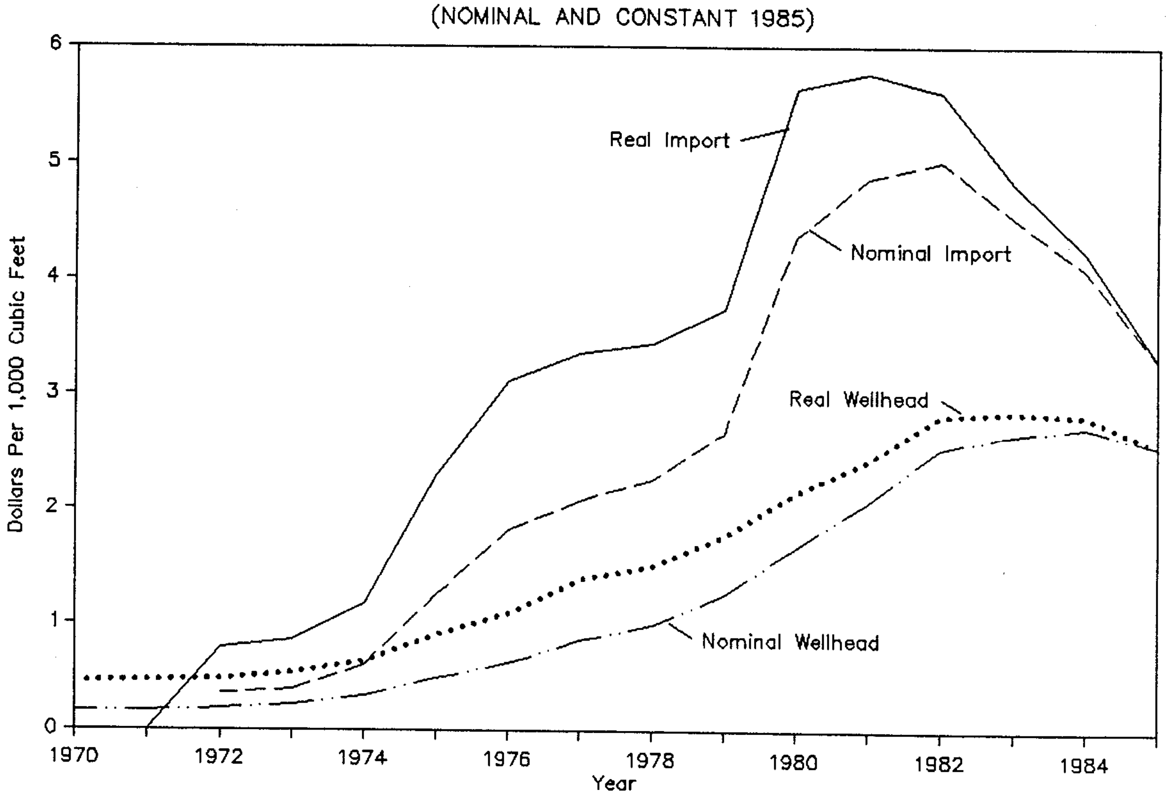


FIGURE 5
NATURAL GAS PRICES
(NOMINAL AND CONSTANT 1985)



petroleum and natural gas production and consumption. At the present time, the national petroleum market is directly linked to the world petroleum market by price and supply. The situation is characterized by excess productive capacity in the world market, a strong desire by exporting nations to sell petroleum to meet financial obligations, a time of relatively slow economic growth, and declining petroleum prices. The domestic natural gas industry is currently working off surplus reserves added during the early 1980s, but depressed prices have resulted in a sharp reduction in drilling which could have serious implications for future domestic gas production.

Implications of the petroleum price slide during the first half of 1986 are not yet fully discernable. Middle eastern nations have been unable to reach accord in setting and adherence to self-imposed oil production quotas. In the past, Saudi Arabia has taken the position as swing producer for OPEC, and thereby reduced production to maintain quota levels. However, Saudi Arabia changed policies in 1986 to concentrate on achieving a "fair market share" of the international petroleum market with little concern for output quotas. The strategy behind this policy was not disclosed, but speculation as to the potential motivation and results of this action includes:

1. Saudi Arabia is making a show of strength to discipline OPEC members that have cheated on production quotas and prices with hopes of bringing member and possibly non-member nations together as a unified market group;

2. Saudi Arabia sought to increase revenue, but underestimated the effects additional production would have on price;

3. Saudi Arabia is flooding the world oil market in an effort to eliminate producers with higher costs of production and thereby reduce competition;

4. Saudi Arabia is acting to reduce prices and stimulate growth in petroleum demand to reverse conservation efforts initiated in the late 1970s and 1980s.

In any event, a tremendous amount of uncertainty exists in the national petroleum industry, which has resulted in major financial restructuring. The most evident signs of restructuring are major employment reductions and reduced capital expenditures for exploration and drilling.

The interest in mineral exploration and possible development in this refuge is driven by the future national demand for oil and gas, the cost and availability of domestic supplies, and the hydrocarbon potential of the area. The rate of future economic growth and hydrocarbon prices will be the major determinants of petroleum and natural gas demand. Future domestic production is dependent on resource availability and market prices. However, political forces are having an increasingly important effect on world oil prices, which will ultimately dictate future market conditions. The instability in the world oil market results in tremendous uncertainty in predicting future hydrocarbon prices and market conditions. Table 1 presents three recent crude oil and natural gas price forecasts by the United States Department of Energy, a private research firm, and a major oil company. The prices shown in these forecasts are significantly lower than previous forecasts completed earlier in the 1980s. The range of oil prices projected in these forecasts is $18.00 to $42.00 (constant 1984 and 1985 dollars) per barrel in the year 2000. The high price range is approximately equivalent to the average annual refiner's acquisition cost of imported crude received in 1981 and 1982 (constant 1984 dollars). The range of prices projected for the year 2010 is $47.00 to $67.00 per barrel. These prices would be substantially above the peak levels paid in the early 1980s. Natural gas prices are projected to range between $4.10 and $5.50 per thousand cubic feet (MCF) in the year 2000, and $6.00 to $9.10 per MCF in the year 2010. The magnigude of projected natural gas price increases is similar to forecast changes in world oil prices.

Projections of future domestic petroleum and natural gas demand and supply conditions is presented in table 2. All three forecasts projected an upward trend in petroleum demand above current levels. Petroleum consumption is projected to range from 15.9 to 18.1 MBPD in the year 2000, and possibly increase to 19.4 MBPD by the year 2010. In comparison, domestic petroleum production is projected to decline to levels ranging from 6.1 to 8.9 MBPD by the year 2010. Domestic natural gas demand is projected to increase to a level ranging from 17.1 to 20.4 TCF per year by the year 2000 and then decline to a level of 16.7 to 18.3 per year by 2010. Domestic gas production is projected to follow a similar trend with domestic oil production and decline to levels ranging from 13.9 to 15.0 TCF by the year 2010.

Conclusion

National hydrocarbon markets have undergone substantial changes since the early 1970s. Energy conservation trends initiated by real price increases of the 1970s are expected to continue through the end of this decade and possibly beyond. However, future economic growth is expected to result in some increased demand for petroleum and natural gas, while domestic production of these finite resources is projected to decline. As a result, the United States will become increasingly dependent on foreign hydrocarbon sources to meet national requirements. New areas will need to be explored and any economically viable resources that are discovered will need to be brought into production in order to meet domestic needs. The potential contribution of this refuge to national oil and gas production is dependent on its resource potential and the potential cost at which any discovered hydrocarbon resources could be extracted and marketed within the constraints of future oil and gas prices.

TABLE 1

PETROLEUM AND NATURAL GAS PRICE FORECASTS1/

Reference	Crude Oil ($/Barrel) 1990	2000	2010	Natural Gas ($/MCF) 1990	2000	2010
U.S. Department of Energy, 19852/						
Low Economic Growth	20.27	31.31	47.42	2.64	4.13	6.02
Reference Case	22.89	36.75	56.77	2.76	4.80	7.68
High Economic Growth	25.02	42.17	67.12	2.88	5.42	9.14
Data Resources Incorporated, 19862/	16.91	34.32	49.99	1.69	3.80	5.76
Chevron Corporation, 19863/						
Low Case	12.00	18.00	N/A	Rise to parity with fuel oil prices		
High Case	27.50	35.00	N/A			

1/ Some of the price estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.

2/ Reported on the basis of constant 1984 dollars.

3/ Reported on the basis of constant 1985 dollars.

TABLE 2

FUTURE DOMESTIC PETROLEUM AND NATURAL GAS
DEMAND AND SUPPLY RELATIONSHIPS[1]
(See Table 1 for Price Forecasts)

Reference	Demand 1990	Demand 2000	Demand 2010	Supply 1990	Supply 2000	Supply 2010
	Petroleum (Millions of Barrels Per Day)					
U.S. Department of Energy, 1985						
Low Economic Growth	16.1	15.9	15.5	9.8	9.0	7.8
Reference Case	16.7	16.6	16.5	10.0	9.4	8.3
High Economic Growth	16.8	17.0	17.3	10.0	9.7	8.9
Data Resources Incorporated, 1986	16.9	18.1	19.4	9.5	7.3	6.1
Chevron Corporation, 1986	16.0	16.8	N/A	9.2	7.0	N/A
	Natural Gas (Trillion Cubic Feet Per Year)					
Department of Energy, 1985						
Low Economic Growth	18.6	18.8	17.2	17.4	16.1	14.7
Reference Case	19.1	19.7	17.4	17.6	16.3	15.0
High Economic Growth	19.5	20.4	18.3	17.9	16.6	14.7
Data Resources Incorporated, 1986	18.9	18.1	16.7	16.7	15.3	13.9
Chevron Corporation, 1986	17.3	17.1	N/A	N/A	N/A	N/A

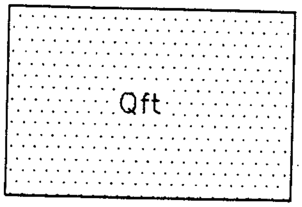
1/ Some of the numeric estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.

APPENDIX D

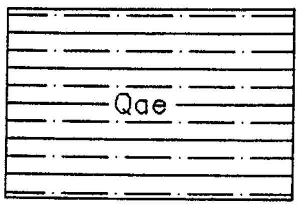
Explanation of Geology for Plate 1

Area of Detailed Geology

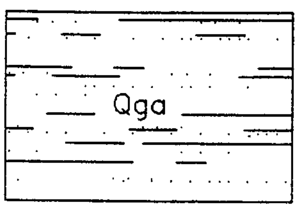
Sedimentary and Metasedimentary Rocks



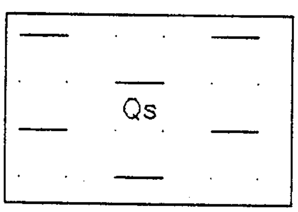
Qft - Flood-plain and tidal flat deposits -- Chiefly silt and fine sand. Gravel on small streams draining upland areas.



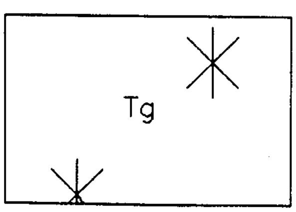
Qae - Undifferentiated alluvial and eolian terrace and slope deposits.



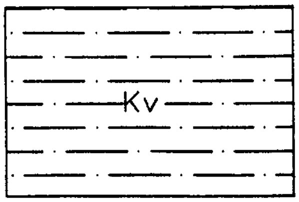
Qga - Undifferentiated glacial drift, alluvium, and eolian deposits -- Chiefly till and outwash gravels mantled by windblown and water-laid silt and fine sand.



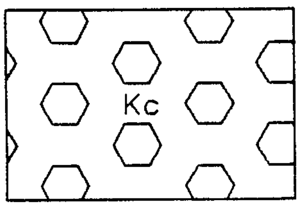
Qs - Eolian sand deposits.



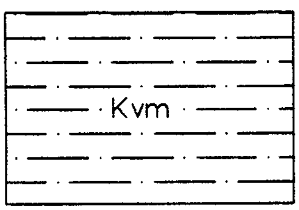
Tg - Gravel and sand.



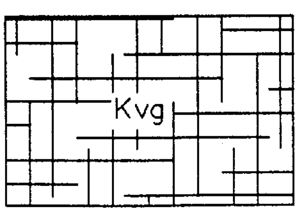
Kv - Conglomerate, sandstone, mudstone, and volcanic graywacke and mudstone -- Conglomerate composed chiefly of white quartz pebbles in a quartzose and micaceous matrix; pebbles of phyllite, schist, greenstone, and chert in subordinate amounts; interbedded with quartzose and micaceous sandstone and mudstone. Poorly sorted dark greenish-gray volcanic graywacke and mudstone. Lenticular masses of pebble-conglomerate composed chiefly of clasts of mafic intrusives, chert, and limestone. Interbedded dark-orange weathering, gray, highly calcareous graywacke and mudstone.



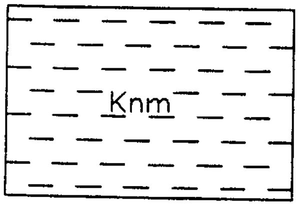
Kc - Igneous pebble-cobble conglomerate -- Massive poorly stratified and poorly sorted conglomerate composed of pebble- to cobble-sized clasts of mafic extrusive and intrusive rocks in a graywacke and mudstone matrix. Clasts of chert and limestone locally abundant.



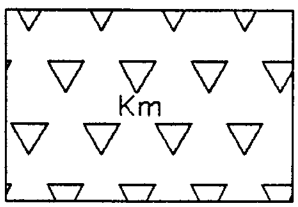
Kvm - Mudstone -- Chiefly medium- to dark-gray mudstone and medium-gray to dark greenish-gray, calcareous and noncalcareous, fine- to medium-grained, volcanic graywacke.



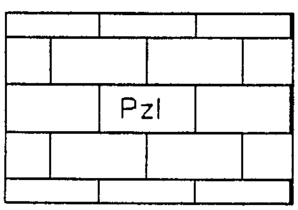
Kvg - Graywacke sandstone, volcanic graywacke, and conglomerate -- Dark greenish-gray to pale-olive tuffaceous and feldspathic fine- to very coarse-grained sandstone. Andesitic volcanic rock detritus, locally includes notable amounts of granitic rock detritus and fine-grained tuffaceous material. Subordinate dark-gray mudstone.



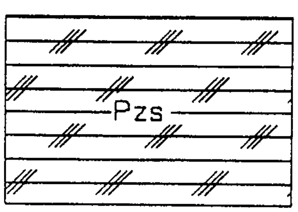
Knm - Nonmarine and marine shale, siltstone, and sandstone -- Nonmarine deposits of dark-gray to olive-gray micaceous shale and siltstone, and light olive-gray to yellowish-orange fine - to coarse-grained cross-bedded sandstone. Littoral and offshore marine deposits of dark-gray shale and siltstone interbedded with subordinate dark greenish-gray fine-grained sandstone in the lower part and light-olive fine- to coarse-grained cross-bedded sandstone in the upper part. Volcanic conglomerate locally.



Km - Metasedimentary rocks -- Small patches of high-grade metamorphic rocks. The metamorphic rocks, which appear to have been derived from pre-existing calcareous and pelitic sedimentary rocks, include calc-silicate hornfels, impure marble and conglomeratic marble, and meta-pelite.

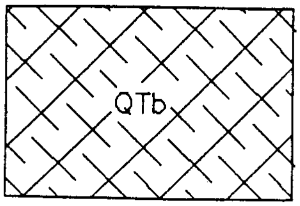


Pzl - Limestone -- Chiefly light-gray, partly recrystallized, reef-like, limestone and dolomite. Minor intercalculated phyllite and schist. May serve as host rock for sulfide mineralization.

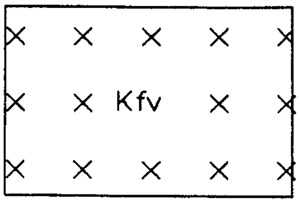


Pzs - Schist and phyllite -- Chiefly light- to dark-gray quartz-mica schist and schistose quartzite and grayish-black phyllite. Subordinate calcareous schist, limestone, chlorite schist, and amphibolite schist. Abundant white vein quartz.

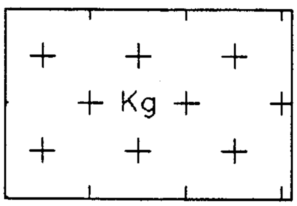
Igneous and Metamorphosed Igneous Rocks



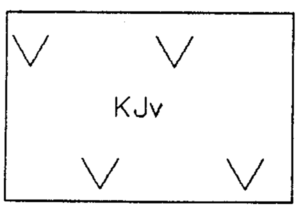
QTb - Basalt.



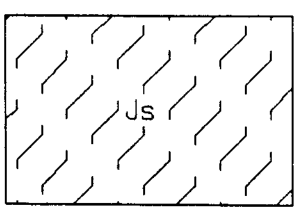
Kfv - Felsic hypabyssal and extrusive rocks -- Small widely scattered bodies of fine-grained intrusive and extrusive rocks including soda rhyolite, latite, quartz latite porphyry, sanidine trachyte, and quartz diorite. Some welded tuff.



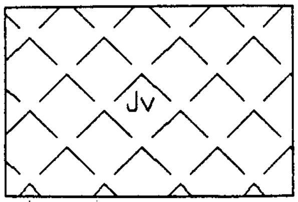
Kg - Granitic rocks -- Syenite, albite granite, monzonite, quartz monzonite, alaskite, granodiorite, nepheline syenite, and biotite-pyroxene monzonite.



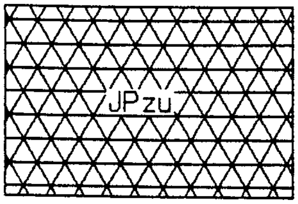
KJv - Andesitic volcanic rocks, porphyritic andesite and basalt, and spilitic pillow basalt and diabase --Includes a wide variety of andesitic flows, volcaniclasitc rocks, and spilitic pillow basalts and diabase. Chiefly andesitic and trachyandesitic crystal and lithic tuffs, and tuffaceous volcanic graywacke, massive andesitic breccia, agglomerate, and conglomerate. Basalts are commonly pillowed and often spilitic.



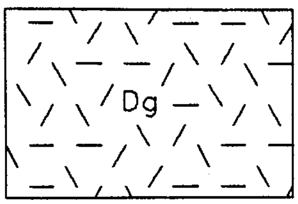
Js - Mafic and ultramafic intrusive rocks -- Includes augite andesite porphyry, augite peridotite, and serpentinite.



Jv - Mafic volcanic rocks -- Chiefly dark greenish-gray basalt flows and diabase intrusives, may be altered.



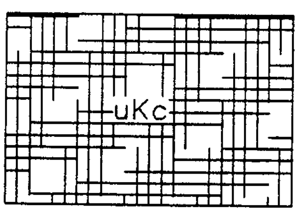
JPzu - Undifferentiated mafic volcanic rocks and phyllite -- Mafic volcanic rocks (Jv) and dark phyllite (Pzs), undivided, in complex fault and intrusive relationships.



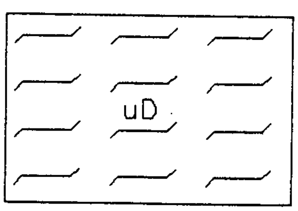
Dg - Granitic orthogneiss -- Metamorphosed intrusive rocks that are predominantly muscovite-biotite granite.

Area of Generalized Geology

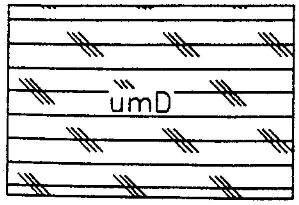
Sedimentary and Metasedimentary Rocks



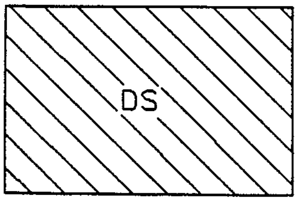
uKc - Upper Cretaceous continental deposits -- Shale and siltstone, with pebble conglomerate around the margins of the Yukon-Koyukuk province.



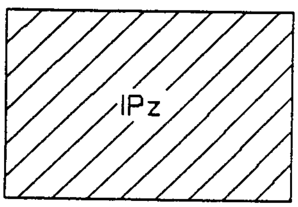
uD - Upper Devonian rocks -- Limestone and dolomite.



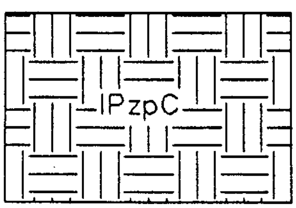
umD - Upper and/or Middle Devonian Rocks --Conglomerate, graywacke, phyllite, shale, sandstone, siltstone, and limestone.



DS - Devonian and Silurian rocks -- Limestone, dolomite, marble, and shale.

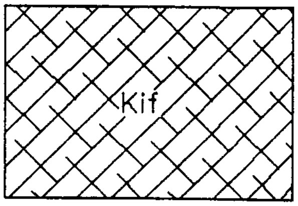


lPz - Lower Paleozoic rocks -- Includes rocks of Cambrian through Devonian age, in places metamorphosed to greenschist and amphibloite facies. Sedimentary rocks include limestone, dolomite, argillite, chert, and graywacke and metasedimentary rocks include schist, quartzite, slate, greenstone, carbonate rocks, and phyllite.

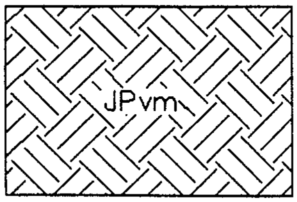


lPzpC - Lower Paleozoic and/or Precambrian rocks --Quartz-mica schist, mafic greenschist, calcareous schist, chloritic schist, phyllite and quartzite.

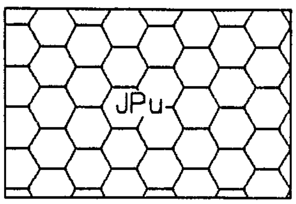
Igneous and Metamorphosed Igneous Rocks



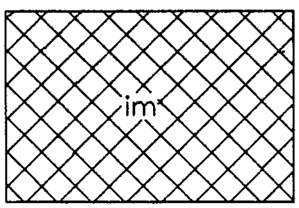
Kif - Felsic intrusive rocks of Cretaceous age --Granite to granodiorite.



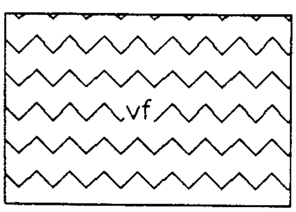
JPvm - Triassic, Jurassic, and Permian volcanic rocks --Predominantly basalt.



JPu - Triassic, Jurassic, and Permian ultramafic rocks.



im - Mafic intrusive rocks of uncertain age --Predominantly gabbro.



vf - Felsic volcanic rocks of unknown age -- Rhyolite to dacite.